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LEVEL II

(10)

STUDY OF RESCUE BOAT PERFORMANCE FOR SELECTED COMMERCIAL VESSEL CASUALTY PROFILES

DEPARTMENT OF TRANSPORTATION • UNITED STATES OF AMERICA

MAY 1978

FINAL REPORT

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16. Abstract

A methodology is developed in this study for determining functional performance criteria for survival systems in general; it is illustrated, however, specifically for rescue boats. Casualty profiles are developed for rescue boats in man overboard and abandon ship casualties. The casualty profiles are presented as block diagrams. The rationale for each event and relationship contained in the casualty profiles is described. The casualty profiles are then developed into computer simulation programs. The Man Overboard Computer Simulation Model and the Abandon Ship Computer Simulation Model are both programmed in BASIC and designed to run on a Wang 2200 System; with minor modifications, they can be modified to run on any micro or minicomputer system. Effectiveness analyses of rescue boats were performed using both programs to determine the effect of seven rescue boat characteristics on the rescue rate. Tentative rescue boat criteria were derived from these analyses. Test procedures are proposed for determining the degree to which rescue boats meet the functional performance criteria. Recommendations are made for further work in developing rescue boat functional performance criteria. Report No.CG-D-8-78 presents a User's Manual for the simulations and Report No.CG-D-9-78 is a Programmer's Manual for each of the programs.

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PREFACE

This report summarizes work conducted under Contract No.DOT-CG-61276-A by CASDE Corporation under the auspices of the U.S. Coast Guard, with Mr. T.H. Sheehan and LCdr. S.H. Davis serving as the Office of Research and Development's technical representatives for the work performed herein. The program manager was Dr. R. Saucedo. F.J. Nickels served as Naval Architect, R.M. DiJulio as Marine Engineer, and L.B. Brown as the System Analyst.

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1. INTRODUCTION

In recent years, there has been a growing concern within the international maritime safety community regarding the inadequacy of ship's lifeboats and liferafts to perform rescues of people in the water. Various national agencies have been considering the specification of requirements for a boat for rescue work. Such requirements may be considered for inclusion in the next revision of Chapter III of the Safety of Life at Sea (SOLAS) Convention. At the next revision, requirements will be written in terms of survival system functions rather than in terms of hardware requirements.

A number of agencies around the world are currently conducting research and development programs to develop a rescue boat according to requirements which are generally held to be relevent. There has not been any effort, however, to systematically and objectively derive functional requirements for rescue boats. This project, consequently, was carried out to meet this need.

1.1 Summary

This report presents the results of a study performed by CASDE Corporation for the U.S. Coast Guard to:

1) develop casualty profiles for commercial vessels to support studies of rescue boat performance criteria,
2) formulate such rescue boat performance criteria and related test procedures, and
3) establish a methodology for developing performance criteria for survival systems in general.

The results, conclusions, and recommendations of this study are presented in section 2 in summary form.

1.1.1 Methodology for Performance Criteria

The method of approach taken in performing this study is presented in Section 3. That section discusses the methodology for developing vessel casualty profiles; even though it delineates the development of such profiles specifically for the construction of rescue boat performance criteria, it should be viewed as a generalized approach in which the essential steps are:

1) Collect and analyze case histories of the relevent casualty types;
2) Formulate casualty scenarios using either block diagrams or fault trees based upon that understanding;
3) Identify events, time durations, and sequences that are quantifiable from statistical data;
4) Develop other necessary quantifications based on engineering principles and mature judgement;

At this point, the methodology must become survival equipment type specific. The remaining steps then are:

5) Simplify the casualty scenario to focus on the appropriate survival equipment to be studied, e.g., lifeboats, liferafts, personal floatation devices, fire extinguishers, survival suits, man overboard detectors and/or locators, etc. This is a critical step and one which requires sound judgement in selecting the appropriate survival equipment parameters or characteristics for study. Criteria for selecting such parameters include that:
   - they be meaningful to the outcome of the analysis,
   - they are expressable in terms of the outcome of a specific event, and
   - they are parameters which can be measured or readily determined for the survival equipment.
6) Develop the appropriate computer simulation using the diagrams formulated in step (2) as flow diagrams;
7) Perform an effectiveness analysis whereby the parameters which characterize the selected survival system

element are varied to optimize a stated payoff function such as "rescue rate";

8) Prepare the test procedures required to properly quantify the survival system parameters; and
9) Prepare the results in appropriate documentation.

1.1.2 Casualty Profiles

Two generalized casualty profiles have been developed in this project to support studies of rescue boat performance: one for evaluating man overboard situations and the other for investigating ship abandonment due to nine different types of casualties. The profiles depict the numerous events, time durations, and sequences necessary to realistically describe typical scenarios which occur in man overboard and abandon ship situations; the profiles are based on numerous case histories and assumptions involving engineering judgement. Wherever possible, factual statistics were used to develop the profiles to the level of detail necessary to support studies of rescue boat performance criteria.

An overview of these casualty profiles is shown in Figures 4-1 and 4-3; detailed profiles are depicted in Figures 4-2 and 4-5 in block diagram form. The block diagrams are used as flow diagrams to develop the corresponding computer simulations. The profiles are considered reasonable real-world approximations sufficient for the purposes stated.

Casualty profiles were developed to include the following ship types:

1) Tankers
2) Containerships
3) LNG Ships
4) Fishboats
5) Tugs
6) Barge Carriers (LASH)

7) Great Lakes Bulkers
8) Ferries

They were also developed to include the following casualty types:

1) Fire
2) Collision and Fire
3) Collision and Sinking
4) Explosion and Fire
5) Explosion and Sinking
6) Structural Failure
7) Grounding
8) Capsizing
9) Foundering

A detailed explanation of these casualty profiles, the statistics used, and the assumptions made is given in Section 4.

1.1.3 Computer Simulation

Two distinct computer simulations were developed in accordance with the casualty profiles used. The simulations for the man overboard and the ship abandonment studies were developed in a BASIC* language for use on the Wang 2200 minicomputer system; they can be readily modified for use on any mini or microcomputer system which has a BASIC* capability. The advantages of such a development include economies of operation, flexibility, simplicity of use and minimization of input errors. Both simulations have an interactive dialogue programmed so that anyone, regardless of his degree of programming knowledge, can operate the simulations. The simulations are described in Section 5; Report No.CG-D-9-78, the Programmer's Manual, contains a detailed explanation of all the computer programs. Report No.CG-D-8-78, the User's Manual, contains the explanation required for the survival system analyst to operate both computer simulations.

*BASIC is a registered trademark of Dartmouth University

1.1.4 Effectiveness Analysis

Section 6 presents the results of the study. Figures, determined from the multitude of computer simulation runs, which depict the effectiveness of the various rescue boat characteristics for the different casualty types, are discussed; they form the basis for the conclusions and recommendations given in Section 2. The payoff criterion used in this study is to maximize a "rescue rate" defined as the ratio of the number of people saved by the rescue boat to the total number of people in the water.

2. CONCLUSIONS AND RECOMMENDATIONS

The results of this study, in terms of the stated objectives, are:

1) Casualty profiles for commercial vessels have been successfully developed; they are primarily based on casualty records and adequately support studies of rescue boat performance critiera; the profiles depict the man overboard and ship abandonment casualties.
2) A methodology, which is useful for survival systems in general, has been defined for developing performance criteria for rescue boats. The key element in the methodology is a simple-to-use computer simulation.
3) Rescue boat performance criteria and associated test procedures have been studied and tentative conclusions drawn; these are presented in section 2.1 and 2.2 respectively.

2.1 Rescue Boat Performance Criteria

The rescue boat characteristics were determined after a careful analysis of both the man overboard and the abandon ship profiles. Only those characteristics which influenced the rescue rate were studied; in most cases, events related to the rescue boat and their associated sequences were combined to reduce complexity and to express the effects of a rescue boat and its launching system in a more meaningful way. For example, the turns, accelerations, decelerations, etc., which must be performed by the rescue boat in proceeding from the side of the ship to a man in the water were combined into a single event; the characteristic which measures the rescue boat's ability to perform this event is its "mean time to perform the standard maneuver"; this mean time is a measurable quantity. The same is true for the rescue boat parameter the "mean time to pick-up one survivor". Each of these functional performance parameters combines a myriad of specific rescue boat characteristics, such as: boat resistance, propulsion, seaworthiness, crew performance, etc.

In the man overboard (MOB) and abandon ship studies, sixteen rescue boat characteristics were evaluated; these studies were performed for eight ship and nine casualty types under differing environmental conditions. As a consequence, there are over 14,000 possible combinations of variables available for study. Clearly, not all combinations warrant study. To stay within the bounds of this project, only a representative sample of the possible combinations were analyzed; consequently, the conclusions presented here must be considered tentative and subject to modification based on further analyses.

The more significant conclusions reached are:

1) In only 10% of the MOB cases where the man is not seen falling overboard is the MOB even alive when the ship or boat returns to their approximate position. Clearly, since the rescue boat can impact only 10% of these cases (approximately 4% of the total MOB cases), greater emphasis should be placed on early MOB detection and alarm methods and on personal floatation and protection "suits" which are convenient to wear and which also increase the MOB's time to remain afloat and survive.
2) In 42% of the MOB cases where the man is seen falling overboard (approximately 27% of the total MOB cases), the present equipment provides an effective rescue mechanism.
3) In about 11% of the total MOB cases, the slowness of the rescue effort was the primary cause of lost lives. This "lost lives" rate is influenced primarily by the time required for launching the rescue boat and for performing the standard maneuver.
4) Improvements in the launching system, i.e., by reducing the time required to launch the rescue boat, can result in a 1% improvement in the rescue rate for every minute saved in the time to launch, up to a maximum of about 4%. This improvement can be achieved by simpler launch mechanisms, e.g., single falls, and better crew training.

5) Rescue boat capacity, in general, should be between 5 and 10; this requirement is driven by the abandon ship situations. Capacity in excess of ten is not necessary simply because the number of people in the water due to ship abandonment is usually much less than ten. Capacity lower than five results in a sharp drop in the rescue rate (about a 2% drop in the rescue rate for every capacity number reduced). The situation is unique for passenger vessels which, under present regulations are not required to have redundancy in basic survival craft capacity. For these vessels, the capacity of the rescue boat can have a significant influence on the survival rate to the extent that it provides redundancy for the basic outfit of lifeboats and/or liferafts.

6) The "rated heel angle of the davits", i.e., the heel angle at which the davits are fully operational, has been found to offer significant potential for improvement of the rescue rate. Studies indicate that for a one (1) degree improvement in the rated heel angle beyond the currently accepted value of 15 degrees, that approximately a 2.5% increase in the rescue rate would result.

7) Improvements in seaworthiness beyond current USCG lifeboat standards improve the rescue rate only slightly but that worsening of the rescue rate would begin to be significant if seaworthiness standards are relaxed. The conclusion is that while reasonable efforts should be made to maintain or improve seaworthiness, extraordinary improvements in seaworthiness are not as important as improvements in other areas of rescue boat performance.

Conclusions 4 through 7 are drawn from the abandon ship studies.

8) In the limited ship abandonment studies conducted, i.e., for tankers and ferries only, the rescue rate was found to increase by about 6.5% with the use of a second rescue boat. This is due primarily to the redundancy provided which greatly reduced the likelihood that no rescue boats would be available due to damage caused by the casualty, e.g. in collisions and/or fires. A more detailed, cost effectiveness analysis is required to arrive at a more definitive conclusion.

9) The rescue rate in ship abandonment situations can be increased by as much as 12% for every minute reduction in the rescue boat characteristics of "mean time to pick-up" (MTTP). Extensive analyses were made of rescue boat performance in ship abandonment for eight casualty types. The MTTP and also the "mean time to perform the standard maneuver" characteristics, which basically quantify the agility of rescue boats, significantly impact the rescue rates and should consequently be improved. The effect of the MTTP on the rescue rate is more pronounced for ship casualtites which result in greater numbers of people in the water, most notably in explosion and fire casualties.

The MTTP and the "mean time to perform the standard maneuver" are characteristics which can be determined by tests of the actual boats.

2.2 Rescue Boat Test Procedures

Test procedures to determine the rescue boats ability to satisfy stated performance criteria are required. Only those additional procedures not covered by existing regulations are mentioned here; the additional test procedures required are those necessary to quantify the three functional performance parameters proposed as measures of the rescue boat's speed and agility; these are the dynamic quantities of "mean time to perform the standard maneuver",

the "mean time to pick-up one survivor" (MTTP), and the boat speed in waves. These characteristics must be measured dynamically on a standarized course. The first two functional performance parameters are very similar; each requires that the boat perform a number of short maneuvers on a calibrated course in a moderate seaway. The third parameter can be measured in a straight-forward way.

Further details of the test procedures can be found in Section 6.

2.3 Recommendations

The results of the first phase of the development of rescue boat performance criteria by means of computer simulation of casualty profiles has been successful. Additional effort is required, however, before the functional and the associated testing requirements for rescue boats for all ship types are developed sufficiently for incorporation in the regulations; the developmental steps are described below.

1) An effectiveness analysis utilizing the full capabilities of the MOBCSM and the Abandon Ship Computer Simulation Model (ASCSM) should be conducted. The conclusions drawn from the rescue boat effectiveness studies to-date should only be considered as tentative with additional work required to produce more substantive conclusions regarding rescue boat performance criteria.
2) Tests should be conducted with various types of boats currently used as rescue boats, i.e., standard lifeboats and the 26 foot motor whaleboat, to determine appropriate baseline values for the "mean time to perform the standard maneuver" and the "mean time to pick-up one survivor". Since there has been no prior experience in the use of these parameters, the estimates used in the analyses are somewhat speculative; this early testing would also provide experience with the test procedures.

3) Effort should be continued to extend and improve the present versions of the MOBCSM and the ASCSM. Areas for improvement include:
   - -- modeling the effects of crew training, skill, fatigue, etc. on rescue boat operations;
   - -- modeling the environmental conditions as functions of the casualty type as well as the ship type, e.g., relating structural failures more closely to storm conditions and collisions to reduced visibiltiy;
   - -- incorporating the effects of panic during ship abandonment;
   - -- determining constraining relationships within rescue boat characteristics so that a more meaningful optimization can be made.

Other recommendations are:

1) A similar study program should be started to include other elements of survival systems, e.g., lifeboats, liferafts, PFDs, survival suits, etc. This additional effort would lead to the capability for determing functional requirements for all elements of survival systems;
2) A study effort should be started to more closely relate the specific casualty development with the ship abandonment process; and
3) Additional effort should be focused in the areas of man overboard detection and increased survival time in the water.

3. STUDY APPROACH

The general approach used in this study is discussed below. Although it specifically addresses the means for developing functional performance criteria for rescue boats and the required test procedures, it should also be viewed as defining the methodology for developing performance criteria in general.

3.1 Analyze Casualty Case Histories

The first step in the process was to study case histories of the relevent casualty types from such sources as the Marine Board of Investigation reports, Coast Guard casualty records, classification society reports, interviews with casualty witnesses or participants, interviews with ship owners and operators, etc. This provided a reasonable understanding of how such casualties develop.

3.2 Develop Casualty Profiles

It was recognized at the outset of the study that rescue boats were factors in two classes of casualties: man overboard and ship abandonment. The understanding gained in the first step indicated that the two classes of casualty were sufficiently dissimilar to warrant the development of separate casualty profiles. It was also evident that it would not be possible to define an adequate casualty profile for abandon ship casualties based on casualty statistics alone since the required statistics simply did not exist. The casualty profiles were developed as block diagrams depicting the sequences of events, including alternative sequences, based upon the knowledge and understanding of what does and can take place during each particular casualty.

In the construction of the casualty profile block diagrams, it was necessary to strike a balance between the degree of detail to be presented and that required to provide completeness for the task intended. This was achieved by limiting the events depicted

to those whose outcome was influenced by the variable parameters selected for study and those necessary for proper sequencing of events in the model. Sequences of events which were not influenced by the variable parameters were combined wherever possible.

A critical element of the process just described was the selection of the rescue boat parameters or characteristics. It was necessary that they were: first, meaningful to the outcome of the analysis; second, that they were expressable in terms of the outcome of a specific event; and third, that they were parameters capable of being measured on a particular boat. It is notable that traditional parameters such as length, beam, weight, horsepower, etc. were not selected but functional parameters such as the "mean time to pick up one survivor" were. The selection of appropriate rescue boat characteristics for study reflects the outcome of numerous discussions with manufacturers and users of survival craft.

3.3 Identify Items Quantifiable From Statistics

Following the development of the block diagrams, the various events, time durations, and the relationships determining the outcome of each event which were quantifiable using casualty statistics were identified. Needless to say, a great deal of the information required was not available; whatever existed that was useful in the various casualty records or in other study reports was used.

3.4 Develop Other Necessary Quantifications

Where statistical data was unavailable or unreliable, the required relationships and other information were developed by means of engineering analysis and sound judgement. In many cases, the assumptions made could not be tested since in some of the cases, they reflected subjective feelings. It was decided, however, to proceed and identify these assumptions so that others, with perhaps a different perspective, could modify them according to their specific views.

3.5 Develop Computer Simulation

Simulation by means of a computer was the method selected for conducting the effectiveness analysis of the rescue boat characteristics because the large number of events and the random nature of many of these events precluded the validity of analysis by means of a typical or "average" casualty.

The block diagram depicting the man overboard casualty profile was used as a flow diagram to develop a computer simulation using "BASIC" as the computer language for implementation on a Wang 2200 minicomputer system. The abandon ship casualty profile was also simulated completely on the Wang 2200 System. The simulations were structured for interactive communication with the operator, simplicity of operation, and economy of usage.

3.6 Effectiveness Analysis

The overall measure of merit used in the analyses is the "rescue rate", i.e., the ratio of number of people saved by the rescue boat to the total number of people in the water. Each model was exercised to determine the effect of changes in selected rescue boat characteristics on the rescue rate. In general, only one parameter was changed in each simulation run. A baseline case was defined which conforms to current ship's lifeboats used as the rescue boat. Changes in the rescue rate were compared to the rescue rate determined for the baseline case. The results are displayed in graphs and charts as appropriate to enable the effects of changes of alternative rescue boat characteristics to be compared. Functional performance criteria were derived from analysis of these charts and graphs.

4. CASUALTY PROFILE DEVELOPMENT

4.1 Man Overboard Model

The Man Overboard Model is intended to provide a realistic profile of man overboard situations to enable the effectiveness of alternative rescue system configurations to be studied. In constructing the profile, emphasis was placed on modelling the aspects of the man overboard situation which involve the rescue boat. Other aspects of the man overboard situation which do not involve the rescue boat, for example the circumstances which caused the man to enter the water or his medical treatment after rescue, have not been modeled.

The Man Overboard Profile is described using a conventional block diagram format; this diagram forms the basis for a computer simulation. The diagram is consequently referred to as the Man Overboard Computer Simulation Model (MOBCSM).

4.1.1 Measure of Performance

The central measure of performance of the rescue system in the (MOBCSM) model is whether the rescue effort is applied to the man in the water before he expires. The physical ability of the system to actually perform the rescue is, of course, also modeled. In each simulation, determining whether the rescue effort is successful or not is made by comparing the simulated survival time of the man in the water with the simulated time for the rescue boat to arrive at the man's position in the water. The MOBCSM model is therefore composed of two sets of routines: one set to determine the man overboard's survival time and another to determine the rescue system's performance time.

4.1.2 Two Distinct MOB Situations

Consideration of the man overboard (MOB) problem, including a study of man overboard case histories, reveals that the tasks which a rescue system is called upon to perform in a man overboard situation fall into two categories depending upon whether

NOMENCLATURE

MAN OVERBOARD MODEL

Symbol	Description
T_{LS}	Time Since MOB, Not Seen Entering Water, Last Seen
T_M	Time To Miss MOB, Not Seen Entering Water
T_N	Time To Notify Bridge Of MOB
T_T	Time To Turn 180°
T_{S1}	Time To Survive With Floatation
T_{S2}	Time To Survive Without Floatation
T_{HYP}	Time To Die From Hypothermia
ΔT	Time To Complete One Search Pass
T_{RPT}	Time For Rescue Boat Crew To Report To Boat
T_P	Time To Prepare Rescue Boat For Launch
T_L	Time To Launch Rescue Boat
T_{SL}	Time For Ship To Slow To Boat Launch Speed
T_{SLO}	Time For Ship To Stop From V_S
ΔT_{SC}	Increment Of Search Time
T_{MN}	Time To Maneuver Ship To MOB
T_{MB}	Time To Maneuver Rescue Boat To MOB
T_R	Time To Retrieve MOB From Water
T_{RETB}	Time For Rescue Boat To Return To Ship
T_M/T_{LS}	Ratio Time To Miss MOB to Time Last Seen
u_{HYP}	Max. Time to Die From Hypothermia
ℓ_{HYP}	Min. Time To Die From Hypothermia
μ_{HYP}	Mean Time To Die From Hypothermia
σ_{HYP}	STD, DEV. Of Time To Die From Hypothermia

Symbol	Description
S	Time Of Year
h_w	Significant Wave Height
t_w	Water Temperature
μ_{tw}	Mean Water Temperature
L	Ship Length Feet
V_s	Ship Speed At Time Bridge Notified of MOB
μ_{hw}	Mean Significant Wave Height
σ_{hw}	STD. DEV. of Wave Height
α_s	Mode of Wave Heights in Mid-Summer
α_w	Mode of Wave Heights in Mid-Winter
NE	Navigational Error
a	Lateral Navigational Error/Ship Length
b	Angular Navigational Error
d_{VS}	Distance of Visability From Ship
VIS	Distance of Environmental Visibility
N	No. Of Opportunities For Ship To Pass MOB Before He Dies
K	No. Of Times Ship Has Passed MOB Without Sighting Him.
μ_p	Mean Time to Prepare Boat For Launch
σ_p	STD DEV. Of Time To Prepare Boat For Launch
h_{LIM}	MAX. Wave Height That Rescue Boat Can Be Launched.
μ_L	Mean Time To Launch Rescue Boat
σ_L	STD. DEV. Of Time To Launch Rescue Boat
V	MAX. Ship Speed That Rescue Boat Can Be Launched

Symbol	Description
P_1	Probability man is seen falling overboard.
P_2	Probability that man who is seen falling overboard is wearing a PFD.
P_3	Probability that man who is not seen falling overboard is wearing a PFD.
P_4	Probability that man who was seen falling overboard and is not wearing a PFD actually receives floatation thrown to him.
P_5	Probability that ship is in restricted waters or is otherwise prevented from returning to the man in the water.
P_6	Probability that, given the rescue boat's characteristics, it would be used as the primary vehicle to search for the MOB.
P_8	Probability that when ship returns on second or succeeding passes to MOB's true position that he is seen (if he is, in fact, still afloat).
P_9	Probability that MOB who was seen falling overboard is in sight when rescue boat returns to man's presumed position (when ship is restricted from returning to man's position).
P_{10}	Probability that attempt will be made to recover the MOB from the water directly onto the ship.
P_{11}	Probability that recovery of MOB from the water directly on the ship is successful.
P_{12}	Probability that man who was seen falling overboard is still in sight when ship completes maneuver to return to him.
P_{13}	Probability that recovered MOB and rescue boat crew will be transferred from boat to ship while boat is still in water.
P_{14}	Probability that attempt to remove recovered MOB from boat to ship is successful.
P_{15}	Probability that attempt to recover rescue boat, with MOB and crew in it, back aboard the ship is successful.

the man was or was not seen falling overboard. If he was not seen falling overboard, the ship and/or the rescue boat must first search for the man and then go to his rescue. If the man was seen going overboard, the task is reduced to either rescuing the man or, if he is subsequently lost sight of, searching for the MOB in a predefined area. It was found convenient in constructing the MOBCSM to separate these two situations, i.e. either seen entering the water or not, into two alternative paths. Each path simulates both the man's survival time and the rescue system's performance time.

4.1.3 Overview of the Model

Figure 4-1 shows an overview of the MOBCSM model. For each simulated fall overboard, whether the fall was seen or not it is modeled according to a probability based upon facts gathered from man overboard case histories. If the man is not seen entering the water, then there are three possibilities: either the ship, the rescue boat, or both return to search for the man. If the man is seen entering the water either the ship or the rescue boat returns to the man. Each of these five possibilities involves a different sequence of events and result in different rescue times depending upon the ship's and rescue boat's characteristics. They are therefore modeled in the MOBCSM with separate alternate paths. Finally, provisions are built into the model for recovering the MOB depending upon whether the ship or the rescue boat returned to the man in the water and upon the ship's characteristics.

As each man overboard incident is simulated, a simulated survival time is generated from the appropriate statistical distribution imbedded in the program. At any point along the sequence of events path taken in the particular simulation, if the accumulated time exceeds the survival time before the man is successfully rescued, a loss of life is recorded. A saved life is only recorded if a successful simulated rescue is accomplished in shorter time than the simulated survival time for the individual.

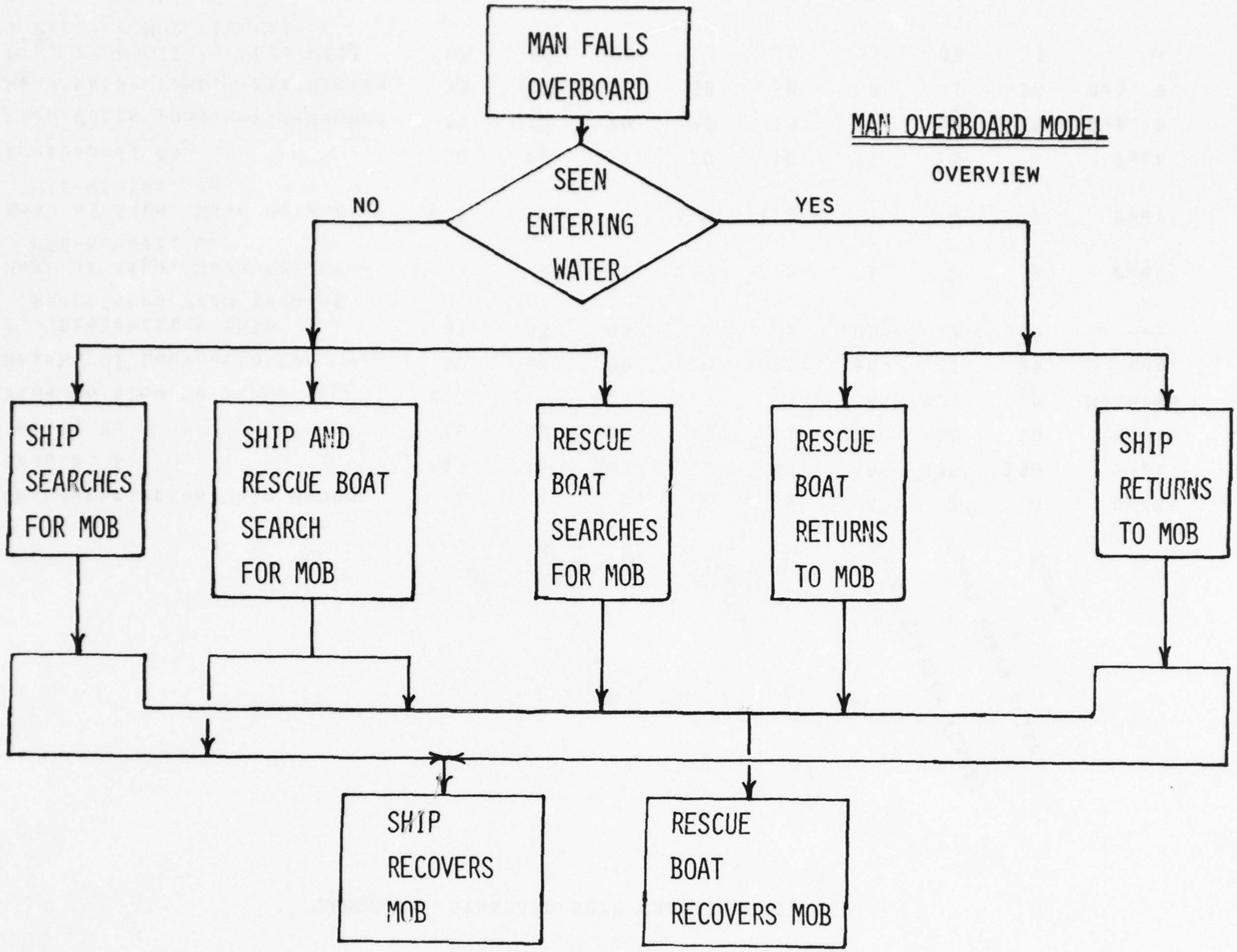

MAN OVERBOARD MODEL
OVERVIEW
MAN FALLS OVERBOARD
SEEN ENTERING WATER
NO
YES
SHIP SEARCHES FOR MOB
SHIP AND RESCUE BOAT SEARCH FOR MOB
RESCUE BOAT SEARCHES FOR MOB
RESCUE BOAT RETURNS TO MOB
SHIP RETURNS TO MOB
SHIP RECOVERS MOB
RESCUE BOAT RECOVERS MOB

FIGURE 4-1

TABLE I: STANDARD SHIP CHARACTERISTICS

	Tanker	Containership	LNG	Fishboat	Tug	Barge Carrier (LASH)	Great Lakes Bulker	Ferry	
Characteristics/Ship Number	1	2	3	4	5	6	7	8	UNITS
Length, L	845	710	900	75	150	740	708	150	Feet
Speed, V_S	16	23	20	10	7	21	14	16	Knots
Time To Slow To Stop, T_{SLO}	8.5	2.6	6.4	.5	8	6	9.4	.5	Minutes
Height Of Lookout's Eye, h_{ES}	50	60	90	20	25	60	37	35	Feet
P_5, Probability Ship Restricted From Turning	.05	.05	.05	.1	.5	.05	.2	.15	---
Mode of Sign. Wave Height--Mid-Summer, α_S	3	3	3	2.2	2.2	3	2	3	Feet
Mode of Sign. Wave Height--Mid-Winter, α_W	6.5	5	5	4.9	4.9	5	4	5	Feet
Freeboard, FB_S	10	24	54	10	10	25	13	8	Feet
Mean Water Temp.--Mid-Summer	70	70	70	70	70	70	60	70	Deg. F.
Mean Water Temp.--Mid-Winter	38	38	38	38	38	38	42	38	Deg. F.
P_{10}, Probability Ship Will Recover MOB Directly	.05	.05	.05	.5	.5	.05	.05	.5	---
Mean Navigational Error, μ_Θ	1	1	1	2	2	1	1	2	Deg.

The MOBCSM model is designed to conduct the desired number of simulations of man overboards from a given ship type equipped with a specific rescue boat. The program has established within it a set of charcteristics (relevent to the man overboard situation) for a typical ship of the type specified. These characteristics, as they are established in the MOBCSM, are listed in Table I. The option exists for modifying values of ship length, speed, and navigational heading error if desired. The rescue boat under study is defined by specifying the values of

TABLE II

RESCUE BOAT CHARACTERISTICS

V_0	Boat speed in smooth water (knots)
V_8	Boat speed in 8 ft. waves (knots)
FB_B	Freeboard (feet)
$\emptyset$	Percent of gunwale that is open (%)
h_{EB}	Height of lookout's eye (feet)
μ_P	Mean time to prepare boat to launch (min.)
N_F	Number of falls
S_D	Rated descent speed (feet/min.)
V_L	Max. ship speed that boat can be launched (knots)
h_{LIM}	Max. wave height that boat can be launched (feet)
P_6	Probability that captain would use boat to search for MOB
T_{SM}	Time to perform standard maneuver (min.)
EN	Endurance hours

the 13 rescue boat characteristics listed in Table II. Each of these characteristics is discussed in detail below.

4.1.4 Environmental Conditions

Throughout the model, characterization of various events, e.g., the launch of the rescue boat, depends upon environmental conditions, e.g., the sea state. The environmental conditions are simulated for each man overboard case by using the appropriate parameters of the environmental conditions characteristic of each ship type and the waters in which they typically operate. Thus, the simulated environmental conditions for tugs and fishboats are characteristic of the coastal waters where they typically operate whereas the environmental conditions for tankers and cargo ships are typical of transoceanic trade routes. Environmental conditions simulated include sea state (represented by significant wave height), water temperature, and visibility.

Sea State

Wave distributions at sea have been shown by Jasper (reference 2) to conform to the Rayleigh distribution. The Rayleigh distribution can be fully defined by a single parameter: the mode (see reference 1). Wave height distributions for the important maritime operating areas of the world are given in Ocean Wave Statistics, reference 3, by season of the year. The mode of the mid-summer and mid-winter wave heights, α_s and α_w, respectively, were taken from this publication for typical operating areas for each ship type. The time of year, TOY, is modeled using a uniform distribution between 0 and 1 where 0 denotes mid-summer and 1 denotes mid-winter (whether fall or spring is assumed inconsequential). The mode of the wave height, α_{hw}, is then obtained from the relation:

$$\alpha_{hw} = \alpha_s(1-TOY)+\alpha_w TOY$$

under the assumption that a linear trend of wave heights exists between mid-summer and mid-winter.

Water Temperature

A similar correlation of sea-water temperature with geographical location and time of year was not available. Some such consistent correlation is obviously needed if the model is to avoid simulating summer-type water temperatures at the same time as winter-type sea states. The model was therefore constructed with a similar routine (to that for wave height) for simulating water temperature. The water temperature is modeled using a normal distribution, the mean of which is obtained from

$$\mu_t = \mu_{t_s} - (\mu_{t_s} - \mu_{t_w})TOY$$

where

μ_{t_w} is the mean mid-winter water temperature appropriate for typical operating areas for the ship type, and

μ_{t_s} is the mid-summer water temperature appropriate for typical operating areas for the ship type.

In the absence of more specific data, the mean mid-summer and mid-winter temperatures were assumed the same for all ship types except Great Lakes (fresh water) vessels. The mean mid-summer temperature assumed is 70°F and the mean mid-winter temperature is 38°F. Further assumptions include: 1) a standard deviation of 10°F, 2) a minimum temperature of 28°F (the freezing temperature of salt water) and 3) a maximum temperature of 80°F. For Great Lakes vessels, the mean mid-summer and mid-winter temperatures assumed were 60°F and 42°F, respectively.

Visibility

The third environmental characteristic modeled is the range of visibility. This was assumed to vary according to a Rayleigh distribution with a mode of 5 miles for all ship types and times of the year. Since it is assumed in the model that the absolute range of visibility to a man's head floating in the water is one half mile, the distribution of range of visibility beyond this limit is of no consequence. (The present version of the model does not consider visibility enhancement devices that a man overboard might have available, although such a feature could

certainly be added to test the effect these might have on the survival rate.)

4.1.5 Detailed Description of MOBCSM

The complete MOBCSM model is shown in block diagram form in Figure 4-2. The MOBCSM is divided into three sections:

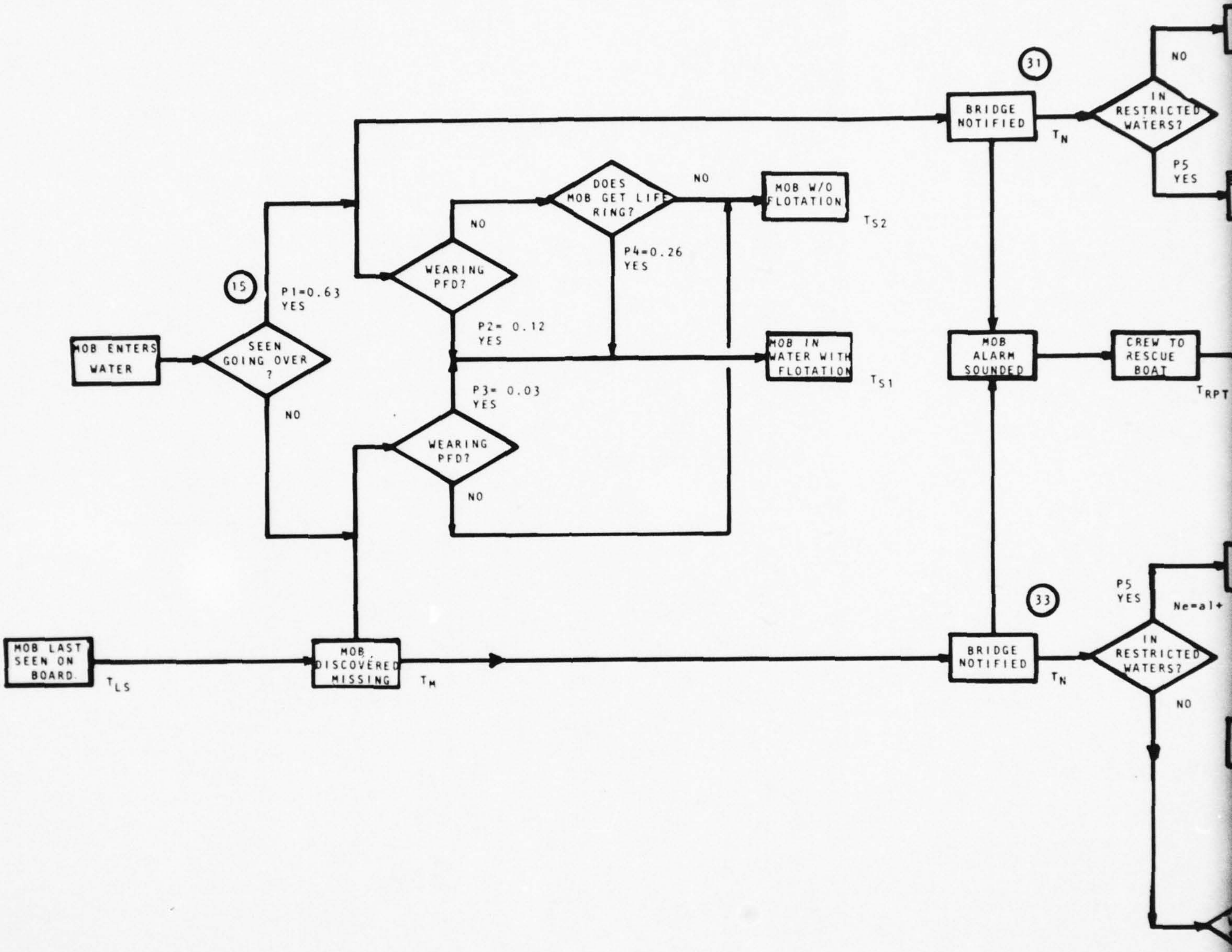
1) a "survival in the water" section which models the MOB's situation and simulates the maximum time available for rescue, i.e. the MOB's maximum survival time in the water,
2) a "shipboard action" section which models the actions taken on the ship in returning to the man, searching for him, and dispatching the rescue boat, and
3) a "rescue boat" section which models the actions of the rescue boat in its attempt to retrieve the MOB from the water.

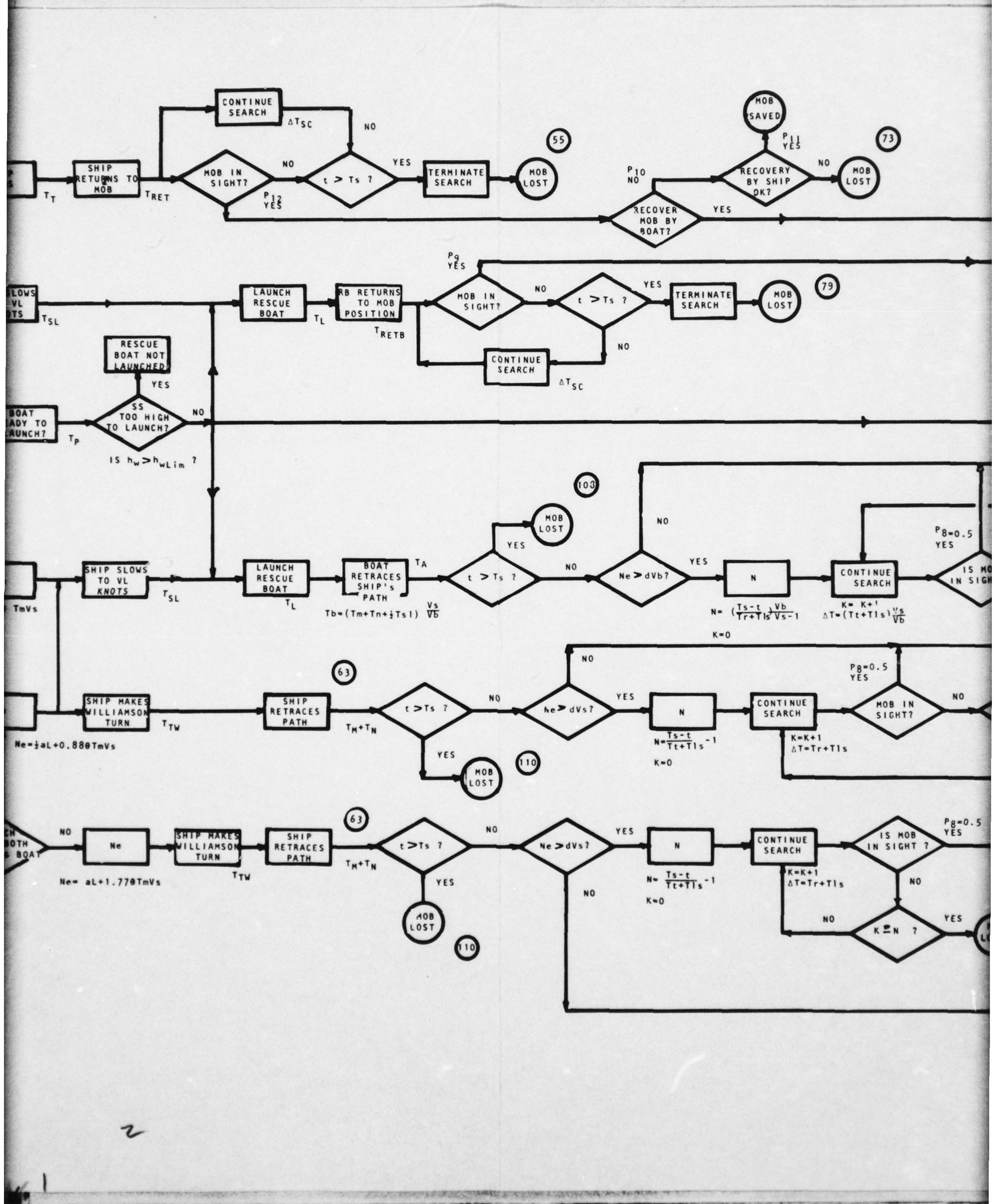
The first event in the scenario is, of course, that of the man overboard (MOB) entering the water. The probability of being seen entering the water is next modeled; this probability, P_1, is based on an analysis of 266 man overboard incidents as reported in Table 47 of reference 4. That analysis showed that the MOB was seen entering the water in 63% of the cases.

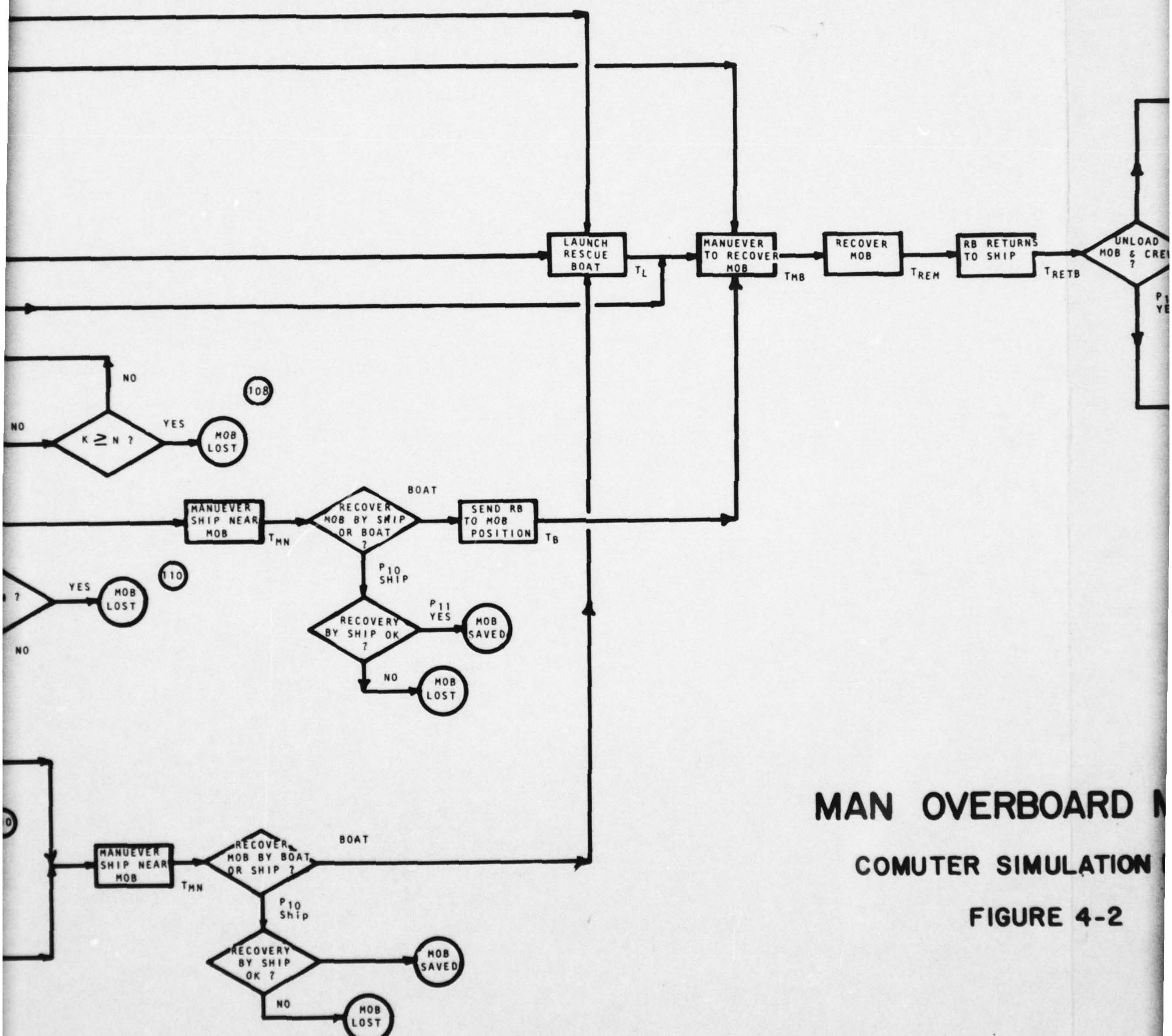
Whether the MOB was seen entering the water or not, his time of survival is assumed to depend on: 1) whether he has floatation and 2) the water temperature. The time of survival is assumed to be the shorter of the following:

1) the time the MOB is able to remain afloat, or
2) the time the MOB is able to survive the effects of hypothermia (i.e. the lowering of the body core temperature due to heat loss).

Medical research has provided relatively good data on the average time that humans can survive in cold water of various temperatures. The life expectancy in cold water incorporated in the MOBCSM model is based on the data presented in Figure 1 of reference 5. It is assumed that the life expectancy at a given water temperature is normally distributed with the width of the band marked


MOB ENTERS WATER
SEEN GOING OVER ?
15
P1=0.63 YES
NO
WEARING PFD?
NO
DOES MOB GET LIFE RING?
NO
MOB W/O FLOTATION
TS2
P4=0.26 YES
P2= 0.12 YES
MOB IN WATER WITH FLOTATION
TS1
P3= 0.03 YES
WEARING PFD?
NO
MOB LAST SEEN ON BOARD.
TLS
MOB DISCOVERED MISSING
TM
31
BRIDGE NOTIFIED
TN
IN RESTRICTED WATERS?
NO
P5 YES
MOB ALARM SOUNDED
CREW TO RESCUE BOAT
TRPT
33
BRIDGE NOTIFIED
TN
P5 YES
Ne=a1+
IN RESTRICTED WATERS?
NO


CONTINUE SEARCH
ΔTSC
NO
MOB SAVED
P11 YES
55
73
SHIP RETURNS TO MOB
TT
TRET
MOB IN SIGHT?
NO
P12 YES
t > Ts ?
YES
TERMINATE SEARCH
MOB LOST
P10 NO
RECOVERY BY SHIP OK?
NO
MOB LOST
RECOVER MOB BY BOAT?
YES
P9 YES
SLOWS VL KNOTS
TSL
LAUNCH RESCUE BOAT
TL
RB RETURNS TO MOB POSITION
TRETB
MOB IN SIGHT?
NO
t > Ts ?
YES
TERMINATE SEARCH
MOB LOST
79
NO
CONTINUE SEARCH
ΔTSC
RESCUE BOAT NOT LAUNCHED?
YES
BOAT READY TO LAUNCH?
TP
SS TOO HIGH TO LAUNCH?
NO
IS hw > hwLim ?
103
MOB LOST
YES
NO
P8=0.5 YES
SHIP SLOWS TO VL KNOTS
TSL
TmVs
LAUNCH RESCUE BOAT
TL
BOAT RETRACES SHIP's PATH
TA
Tb=(Tm+Tn+½Ts1) Vs/Vb
t > Ts ?
NO
Ne > dVb?
YES
N
N= (Ts-t / Tr+Tls)(Vb / Vs) - 1
K=0
CONTINUE SEARCH
K= K+1
ΔT=(Tt+Tls) Vs/Vb
IS MOB IN SIGHT
NO
63
P8=0.5 YES
SHIP MAKES WILLIAMSON TURN
TTW
Ne=½aL+0.880TmVs
SHIP RETRACES PATH
TM+TN
t > Ts ?
NO
Ne > dVs?
YES
N
N= (Ts-t / Tt+Tls) - 1
K=0
CONTINUE SEARCH
K=K+1
ΔT=Tr+Tls
MOB IN SIGHT?
NO
YES
MOB LOST
110
63
BOTH BOAT
NO
Ne
Ne= aL+1.770TmVs
SHIP MAKES WILLIAMSON TURN
TTW
SHIP RETRACES PATH
TM+TN
t > Ts ?
NO
Ne > dVs?
YES
N
N= (Ts-t / Tt+Tls) - 1
K=0
CONTINUE SEARCH
K=K+1
ΔT=Tr+Tls
P8=0.5 YES
IS MOB IN SIGHT ?
NO
YES
MOB LOST
110
NO
NO
K = N ?
YES
2

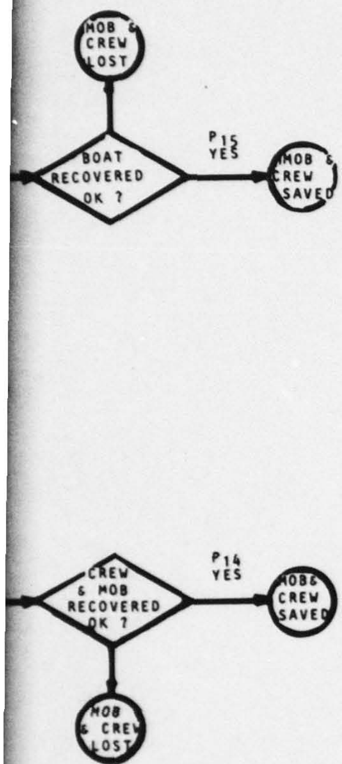


MAN OVERBOARD M

COMUTER SIMULATION

FIGURE 4-2

3


MOB & CREW LOST
BOAT RECOVERED OK ?
P15 YES
MOB & CREW SAVED
CREW & MOB RECOVERED OK ?
P14 YES
MOB& CREW SAVED
MOB & CREW LOST

ODEL

ODEL

4

1

"marginal" in Figure 1, reference 5 equal to to 6.67σ where σ represents the standard deviation. To adapt these data for use in the MOBCSM model, the upper and lower bounds of the "marginal" region in Figure 1, reference 5 were fitted with the following equations:

$$u_{HYP} = t_w(0.000059t_w^2-0.101)+2.25$$
$$\ell_{HYP} = t_w(0.0000081t_w^2+0.0024)-0.1$$

where

u_{HYP} is the upper time limit for survival in hours
ℓ_{HYP} is the lower time limit for survival in hours
t_w is the water temperature in degrees Farenheit.

Then,

$$\mu_{HYP} = 0.5(u_{HYP}+\ell_{HYP})$$

and

$$\sigma_{HYP} = 0.25(u_{HYP}-\ell_{HYP})$$

where

μ_{HYP} is the mean time to die from hypothermia, hours
σ_{HYP} is the standard deviation of the time to die from hypothermia, hours.

The available statistics on the time to remain afloat, with or without floatation and exclusive of hypothermia effects, are much less well developed. Seldom is the length of time in the water known for a person who ultimately drowns. Such statistics that are available are undoubtedly biased toward the more pessimistic times reported in the fatalities. Similarly, statistics on how long persons who were rescued remained afloat are also biased toward shorter times since they do not indicate how much longer the person might have remained afloat.

Figure 6 of reference 4 gives some data on the time to drown that was available from 34 of 266 man overboard incidents studied. The data shows an average time to drown of 3.73 minutes and an

average time for retrieval for those saved of 5.43 minutes. These values must be considered to be biased toward the low side for the reasons just given. In addition, another major bias is due to the fact that this data is based on official U.S. Coast Guard casualty reports. Reporting of successful rescues of man overboards is not required (where significant injury has not also occurred). Presumably there have been many rescues of people who fell overboard; the fact that these rescues were successful can be assumed to be, in part, due to the ability of the survivors to remain afloat for sufficient time.

A further difficulty in deriving conclusions and/or useful statistical parameters from data, such as given in reference 4, is the inter-relationship between being seen entering the water and having floatation. The statistics of reference 4 show that a person who is seen falling overboard is four times more likely to be wearing a PFD than persons not seen falling overboard. The logical explanation for this is that the person was wearing the PFD because of a hazardous activity and/or adverse conditions and that he would not be performing his activities alone for the same reasons. Thus a person who is wearing a PFD is more likely to be rescued not only because he can remain afloat longer but also because the rescue attempt is likely to be carried out more rapidly.

Clearly, no compilation of casualty statistics can provide the parameters to define the distribution of time to remain afloat with and without floatation. Since such data is known to be biased toward the low side, it can be used as a lower limit in using judgement to assign reasonable values to these parameters. The tentative values used in the MOBCSM model, to date, have been a "mean" time to stay afloat of 10 minutes without floatation and 30 minutes with floatation. The survival times are assumed to have a Rayleigh distribution with a mode of 10 and 30 minutes respectively. The word "mean" consequently, actually

denotes the mode in a Rayleigh distribution. The Rayleigh distribution has a minimum of zero which allows the possibility of a person sinking immediatly as a result of wearing heavy clothing.

As discussed on pages 23 and 24, there is very little data available on the time to survive in the water and what is available is very likely to be biased on the pessimistic side.

The best data available to us: in USCG report CG-D-80-75, gave an average time to drown of 3.75 minutes. This was the average of cases with and without floatation and presumably also included hypothermia deaths. Since this was based upon a total of 236 drownings of which 209 did not have floatation, the average must be considered to be representative of persons without floatation.

In the absence of better information, CASDE personnel picked a value of 30 minutes, which is 8 times the tabulated average survival time, as the mean time of survival with floatation, fully recognizing that the intended capability of personal floatation devices is to keep people afloat and alive for much longer periods.

The second event modeled is whether the MOB is wearing a PFD or not. The probabilities of wearing a PFD if he was seen falling overboard, P_2, or if he was not seen falling overboard, P_3, are taken from the data mentioned above in reference 4. The values used are 0.12 and 0.03, respectively. In the case of being seen, the model also simulates the probability of being thrown, and actually getting, a lifering (or some other floatation), P_4. The probability of this, also based on reference 4, is set at 0.26. The model disregards the possibility of a MOB being thrown a lifering if he was not seen falling overboard even though the data shows cases where the MOB is eventually missed, searched for and finally found and then is thrown a lifering. The survival time, T_S, is then determined, as previously mentioned, as the lesser of the time to die from hypothermia, T_{HYP} or the time to stay afloat with floatation, T_{S1}, or without floatation, T_{S2}, as appropriate.

In the cases where the man is seen falling overboard, the next event is that of the bridge being notified. It is assumed that the time to notify the bridge, T_N, is normally distributed with a mean time of one minute, a standard deviation of 0.5 minutes, a minimum of zero (which corresponds to the mate on watch seeing the man fall overboard), and a maximum of 2 minutes.

In the cases where the man was not seen falling overboard, notification of the bridge takes place only after the MOB is discovered missing. Determination of the time interval for the MOB to be missed, T_M, is based on a number of assumptions since statistical data to fix such numbers are not available in casualty records. Data on the time since the man was last seen until he was noticed missing, however, is frequently reported.

The key assumptions made in fixing the time interval T_M are as follows:

1) a person not seen for a threshold period, say 15 minutes, will not be suspected of having fallen overboard,
2) all people on board (POB) are presumed to interact with someone else at least every eight (8) hours,
3) more typically, each POB is presumed to be reasonably active about the ship, either engaged in work or in social activities, so that he will normally interact with others on a more frequent basis, say at least once an hour, and
4) it is equally probable for a POB to fall overboard at anytime since last being seen.

Based on these considerations the time to be last seen, T_{LS}, is hypothesized as a Rayleigh distribution with a mode of 45 minutes, a minimum time of 15 minutes, and a maximum time of eight hours. This presumed distribution has been compared with statistics obtained from U.S.C.G. casualty records and a reasonable verification obtained.

The time to be missed, T_M, is then obtained from the following expression:

$$T_M = (T_M/T_{LS})T_{LS}$$

where the ratio T_M/T_{LS} is postulated to be uniformly distributed between 0 and 1.

The casualty profile continues to evolve once the bridge is notified that a person has fallen overboard; at this time two actions are taken: 1) the "man overboard" alarm is sounded (assumed to take zero time) and 2) the ship begins to be maneuvered to recover the man. Two options for the ship are postulated in performing this maneuver: either the ship turns (commonly in a Williamson turn) or it stops.

If the ship is in restricted waters (such as a narrow channel or river) or is otherwise restricted from turning (such as a tug with tow), the vessel may have no recourse but to stop and depend upon the rescue boat to return to the MOB. The MOBCSM

provides for this possibility by simulating a turn or stop according to the probability that the "ship is in restricted waters or is otherwise restricted from turning", P_5. The value of P_5 is preassigned depending upon the ship type under consideration. Thus, an oceangoing ship like a tanker has a P_5 value of 0.05 but a tug which is considered to be towing half the time has a P_5 value of 0.50.

In the cases where the ship is required to stop rather than turn, the next event in the sequence is the slowing of the ship to the maximum speed at which the rescue boat can be launched, V_L. This speed is a characteristic of the rescue boat and its launching system. Good seamanship calls for the vessel to have some way on (a knot or two) when launching a conventional lifeboat but the speed cannot be much over three or four knots. Thus, even though a boat might be manned and made ready for launch in a very fast time, if the ship takes a long time to slow to the maximum rescue boat launch speed V_L, the launch of the boat will be delayed. Therefore, a high value of V_L as a rescue boat characteristic could be a determinant of good rescue performance on massive ships like tankers.

Many previous research studies, such as reference 6, have shown that the ship deceleration rate is reasonably linear. Therefore, the time for the ship to slow to V_L knots, T_{SL}, is calculated using the expression below:

$$T_{SL} = \frac{V_S - V_L}{V_S} \cdot T_{SLO}$$

where

V_S is the speed of the ship when the bridge is notified and

T_{SLO} is the time for the ship to stop from V_S knots.

The time for the ship to stop from V_S knots is calculated according to the method given in section 15.3, chapter VIII of reference 7 where the appropriate characteristics of each ship type are used.

In the cases where the ship is required to return to the MOB, a Williamson turn is assumed and the corresponding time duration

modeled. A Williamson turn is postulated because this is the standard procedure on many, if not most, vessels. If the man overboard is not in sight, the Williamson turn is the correct maneuver because it will bring the ship back to its original path. If, on the other hand, the bridge has the man in sight, it has the option of terminating the Williamson turn and continuing around in a steady circle toward the man. This has the advantage (over the Williamson turn), of getting to the man faster and of always being closer to him (and therefore less chance of losing sight of him and a shorter distance for the rescue boat at any point in time).

The time to make a Williamson turn, T_{TW}, has been computed for each ship type according to the data given in section 12.6, chapter VIII of reference 7 for appropriate characteristics of the ship representing each ship type.

It should be noted that when the ship has the option to turn or stop it is always better to turn because even if it is desired to slow to launch a rescue boat, a ship will slow at a faster rate while it is turning than if it does not.

Given the current capabilities of rescue (or life) boats, it is the usual practice in a man overboard situation to hold the rescue boat in a ready to launch condition until the ship comes as close as it can to the man. Furthermore, it is considered safer and more expedient on small vessels with low freeboard and good maneuveravility to recover the man directly from the ship. In cases where the rescue boat possesses exceptional capability, however, it might be preferrable to always launch this boat as soon as possible after a man has fallen overboard. Under these conditions both the ship and rescue boat would proceed to the man's assistance. The MOBCSM provides the capability to study such a boat and the policy for its use. This is accomplished in the simulation by setting the probability, P_6, to either 1.0 or 0.0 depending upon whether the simulation program operator wants to allow both the boat and ship searching for the MOB or the conventional way with only the ship searching.

In the cases where the man was seen falling overboard, it is assumed that the ship returns at the same speed at which it was being held prior to the man falling overboard. Consequently, the time period for the ship to return to the MOB's position (after completion of the Williamson turn), T_{RET}, is equivalent to T_N, the interval from the time the man was seen falling overboard to the time when the bridge was notified.

There is some probability, 1-P12, that the ship is not able to locate the MOB when it returns to the man's expected position even though he may still be alive and afloat. This could be due to environmental factors such as sea state, fog, etc. or to an error on the part of the ship in returning to its previous path. It is difficult to determine a value for P_{12} from casualty records since the reasons why the MOB was not seen when the ship returned to the MOB's expected position are unknown. Nevertheless, the simulation model uses a fairly high value of 0.90 for P_{12}. For the other 10% of the times when the man has been lost from sight, the model simulates a back and forth type search in the same general area with the same probability of finding the man, P_{12}, in each increment of search time, ΔT_{SC}, (postulated as 1 minute) provided, of course, that the man is still alive and afloat.

In the simulation the search is effectively terminated as soon as the MOB's survival time has been exceeded in which case the simulation is credited with one "MOB lost". Note that in the real world this wouldn't happen since the personnel on board the ship could continue the search long after the MOB had expired since they would not have any way of determining that fact.

Whenever the ship returns to the MOB's position and the MOB is in sight, the next event in the scenario is to determine whether the recovery is to be from the ship or the rescue boat. The probability that the recovery will be made from the ship, P_{10}, is assumed to be a function of the ship type. The value of P_{10} for example, is higher for a fishboat or tug (P_{10}= 0.50) than

for a tanker or container ship (P_{10} = 0.05). This is necessary to give proper weight to the importance of a rescue boat on a particular type of vessel. If the simulation calls for the recovery to be made from the ship, the probability, P_{11}, determines whether the recovery is successful (the MOB is saved) or not (the MOB is lost). If the recovery is to be attempted with the rescue boat, then the next event in the scenario is to launch the rescue boat.

The scenario, as depicted in the MOBCSM, models the action of the rescue boat crew in reporting to the boat after the "man overboard" alarm has been sounded and determines the time, T_{RPT}, that it takes them to get there. It has been assumed that the rescue boat crew are not on standby, as they would be, for example, on an aircraft carrier; consequently, the MOBCSM model assumes that the time for the crew to report to the rescue boat is normally distributed with a mean time of 1.0 minutes, a standard deviation of 0.5 minutes and a minimum time of zero minutes.

Upon arrival at the boat, the rescue boat crew must prepare it for launch. They must perform various tasks, depending upon the design of the boat and its launching apparatus; for the conventional boat for example, these tasks include removing the boat cover, releasing gripes, swinging the davits out, and starting the engine. The MOBCSM model considers the total time required to perform these preparatory functions as an important rescue boat characteristic, T_P, and has the capability to model particular features extolled by the various survival craft manufacturers for reducing the preparatory time to launch. The rescue boat's time to prepare is assumed to be distributed normally with a standard deviation of half the mean, a minimum of zero minutes, and a mean of μ_{TP}; the mean time is considered a characteristic of the boat and the launching system to be studied.

Finally, the Captain of the vessel may elect not to risk the rescue boat and its crew if the environmental conditions are

considered too severe for the boat (and its launching system). Clearly, this is a subjective judgement based upon the Captain's understanding of the rescue boat's characteristics in the various sea states. No attempt has been make to model this subjectivity. Instead the decision to launch the rescue boat in particular environmental conditions has, in essence, been assumed to be a function of the rescue boat alone. For this purpose the MOBCSM considers the "sea state capability" of the rescue boat as the maximum significant wave height* in which the average captain would be willing to risk launching the rescue boat either because of its probability to be successfully launched or its ability to survive and perform its mission in that sea state. This characteristic is designated $h_{W_{LIM}}$. It is recognized that this may be too simplistic a measure of rescue boat seakeeping capability since the spectrum of the sea state obviously plays a part; e.g., sea states with the same significant wave height but composed of swells in one case and new wind generated waves in another can have significantly different effects on small boat performance. Nevertheless the simplifications and assumptions made are considered appropriate for a first generation model and for the general state-of-the-art in defining rescue boat performance. The boat will not be launched, therefore, unless the simulated significant wave height, h_W, is less than the sea state capability of the rescue boat, $h_{W_{LIM}}$. The boat cannot be launched before T_{RPT} and T_P.

In the cases where the ship cannot (or elects not to) turn, and the man is seen falling overboard, then the rescue boat is launched as soon as the ship has slowed to V_L knots and the boat has been prepared for launch. The time duration to launch the rescue boat is determined using the height of the boat's

---

* Significant wave height is defined as the average of the one-third highest waves which is also the wave height that an observer would be likely to estimate.

stowage above the water (assumed as the vessel's freeboard (FB), a ship characteristic, plus fifteen feet) divided by the descent speed of the falls (S_D); the time to release the falls is assumed to be 0.5 minutes. Survival craft manufacturers promote faster descent speeds as determinants of performance; therefore the MOBCSM model provides the capability to test the effect of this parameter on overall survival rate; free-fall boats can be evaluated as well as single-fall, cradle released boats. The time to launch the boat, T_L, is computed using the following expression:

$$T_L = \frac{FB+15}{S_D} + 0.5$$

Once launched, the rescue boat must return to the MOB's position. The time it takes to do this, T_{RET}, is modeled as

$$T_{RET} = (0.5T_{SL}+T_N)(\frac{V_S}{V_B})$$

since the distance it must traverse is that travelled by the ship from the time the man fell overboard until the ship slowed sufficiently for the boat to be launched; the ratio of ship speed to that of the boat's is intended to correct for the different speed of the rescue boat.

A probability is provided, $1-P_9$, to account for the cases when the MOB is not in sight when the rescue boat arrives in the general vicinity. In these cases, the model is structured such that the boat will perform the same back-and-forth search routine previously discussed for the ship. If the man is found alive and afloat, the boat recovery procedure described in later paragraphs is initiated.

In cases where the man is not seen falling overboard, the ship personnel must estimate the MOB's location and proceed to search that area. The ship personnel can only surmise that the man fell overboard somewhere along the ship's track between the time he was last seen and the time he was found missing. In normal practice, the ship will be returned to the area where the MOB was discovered missing. The MOBCSM accounts for the possibility

that the ship, in completing a Williamson turn, may be laterally displaced from its previous track line by a lateral error of "aL" where "L" is the ship's length in feet and "a" is a normally distributed constant with mean of 0.0 and a standard deviation of 0.50. The model also accounts for a ship heading error of Θ degrees. It is assumed that larger ships, through a combination of better navigational equipment and expertise and better directional stability will have lower heading errors than smaller ships; therefore, Θ is considered a ship type characteristic.

Under the assumption that the ship searches for the MOB at the same speed that it was making at the time the MOB fell overboard, the total lateral error, called the navigational error, NE, is computed using the following expression:

$$NE = aL + 1.77\Theta T_M V_S$$

Since it is of no consequence to the outcome of the simulation whether the lateral error is to port or starboard of the MOB's position, the absolute value of NE is used. In the simulation an option is provided to override the value of the mean heading error, μ_Θ, assigned for a particular ship type if, for example, it is desired to study the requirements for rescue boats on ships equipped with sophisticated navigation systems. The navigational error, Θ, is assumed to be normally distributed with a standard deviation of one half the mean.

If a rescue boat had exceptional capabilities, in particular, if its speed were at least as great as the ship's, it might improve the chance of finding and recovering the MOB if the boat were launched as soon as the man was discovered missing so that both the ship and boat were to conduct independent searches; this capability is provided in the simulation. When this option is used two parallel paths are followed through the model, one representing the search by the rescue boat and the other, the search by the ship. The total width of the search path is therefore the combined width of the paths of the ship and rescue boat. (The width of a search path is considered to be twice the distance of visibility from the vessel.)

It is assumed that communication between the ship and the rescue boat enables the boat to search with no worse a navigational error than that of the ship's. It is further assumed that the MOB is found when the ship and/or rescue boat are in the vicinity and the distance of visibility, d_{VIS}, is less than the lateral navigational error, NE. When both ship and boat participate in the search the effective distance of visibility is the sum of the distances of visibility from each. The performance of the rescue system depends, somewhat, upon which of the two craft actually finds the MOB; this in turn depends upon the speed of each vessel, the relative distances of visibility, and whether the lateral arrangement of the paths placed one or the other closer to the MOB. The interrelationship of the last two factors would be cumbersome to model. A reasonable approximation, consequently is to assign to both a navigational error, NE, of half the value used for the search by a single vessel.

In the cases where the search is conducted using both the ship and the boat, in the cases where only the boat is used, the ship is assumed to slow to the maximum speed at which the boat can be safely launched, V_L. The time required to launch the boat is the greater of the time for the ship to slow to V_L knots, T_{SL}, or for the crew to report to the boat and prepare it for launch, $T_{RPT} + T_P$. As previously discussed, the sea state must also be less than the seaworthiness index of the boat for a successful launch.

If the search is to be conducted using both the ship and the boat, or using only the ship, then the modeling assumes a Williamson turn by the ship; the time for this is modeled as T_{TW}. The modeling of the ship attempting to retrace its path, with its subsequent navigational error, is the same as previously described.

The scenario further assumes that the ship searches the entire distance to where the man was last seen on board. It is recognized that a number of possibilities exist for conducting such

that the ship, in completing a Williamson turn, may be laterally displaced from its previous track line by a lateral error of "aL" where "L" is the ship's length in feet and "a" is a normally distributed constant with mean of 0.0 and a standard deviation of 0.50. The model also accounts for a ship heading error of Θ degrees. It is assumed that larger ships, through a combination of better navigational equipment and expertise and better directional stability will have lower heading errors than smaller ships; therefore, Θ is considered a ship type characteristic.

Under the assumption that the ship searches for the MOB at the same speed that it was making at the time the MOB fell overboard, the total lateral error, called the navigational error, NE, is computed using the following expression:

$$NE = aL + 1.77\Theta T_M V_S$$

Since it is of no consequence to the outcome of the simulation whether the lateral error is to port or starboard of the MOB's position, the absolute value of NE is used. In the simulation an option is provided to override the value of the mean heading error, μ_Θ, assigned for a particular ship type if, for example, it is desired to study the requirements for rescue boats on ships equipped with sophisticated navigation systems. The navigational error, Θ, is assumed to be normally distributed with a standard deviation of one half the mean.

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The scenario further assumes that the ship searches the entire distance to where the man was last seen on board. It is recognized that a number of possibilities exist for conducting such

a search, depending on such things as the Captain's judgement and assessment of a particular situation. For example, he might elect to concentrate the search in the nearer areas where the possibility of the MOB being still alive and afloat is greater. Nevertheless, for the sake of simplicity, no attempt was made to model such subjective reasoning.

The distance to be searched on one search pass is modeled as the ship's speed times the time interval between when the MOB was last seen aboard and when he was found missing. It is assumed that the ship conducts its search at the same speed that it was at when the man fell overboard. Thus, distances along the ship's path are proportional to time intervals and therefore the "length" of a search pass is equal to the time period since the man was last seen on board, T_{LS}, plus the time required to make a 180 degree turn to start the next pass, T_{T180}. The time to make a 180 degree turn is computed using the following:

$$T_{T180} = T_{TW} \cdot \frac{180}{300}$$

since the ship turns through 300 degrees in making a *Williamson* turn.

It is assumed that the ship has only one opportunity to find the man on each search pass. In reality the man's position along the search path is unknown to the ship personnel; in the MOBCSM, however, this information is available for use in computing whether the man is found on any particular pass. The MOB's position, expressed in equivalent units of time (since a constant ship speed is assumed), is T_M minutes from the point where he was discovered missing. After making the Williamson turn the ship must travel a distance $V_S(T_N+T_M)$ to return to the man's position. At this point, the modeling assumes that the MOB will be seen if the navigational error, NE, is less than the distance of visibility, d_{VIS}. If d_{VIS} is greater than the navigational error (NE) of the ship, then it is assumed that the ship continues along a search path of T_{LS} minutes duration.

Note that in this case, there is no mechanism provided for the ship board personnel to realize that they were abeam of the MOB to either port or starboard.

The modeling further assumes that at the end of the first pass the ship reverses its course to one side or the other of the first pass. In reality, the Captain will use his seaman's skills in an attempt to guess the most likely direction to turn but he will have only a slightly better than 50% chance of being right. If he chooses the right direction the chance of seeing the man on the succeeding pass will be high but less than 100%. In the MOBCSM model consequently, it is assumed that the net probability of finding the MOB on each succeeding pass beyond the first, P_8, is 50%.

In the real world, the ship may actually continue the search long after the MOB has drowned and may in fact pass his position many times. In the MOBCSM model, however, the man's survival time is determined early in the sequence of events. Subsequent search passes by the ship after the man's survival time has been exceeded are of no consequence to the outcome of the simulation; therefore the simulation is always terminated as soon as the man's survival time has been reached. This is accomplished by determining the number of opportunities to find the man, N. This is computed by dividing the man's remaining survival time after the search has started (i.e. T_S-t where t is the accumulated time at the start of the search) by the time to complete one search pass, $T_{LS}+T_{T180}$.

The modeling of the search by the rescue boat is identical to that of the ship except that the time to return to the MOB's true position on the first search pass and the time to perform subsequent search passes is modified by the ratio of the ship's speed to the rescue boat's speed. The rescue boat's speed is assumed to be a function of the sea state. This is incorporated in the model by using the rescue boat's characteristic speed in smooth water, V_0, and its speed in a sea state with 8 feet significant wave heights, V_8. The particular speed for a given wave

height, h_W, is modeled using the equation below:

$$V_B = V_0+(V_8-V_0)(\frac{h_W}{8})$$

Note that h_W is a statistical parameter obtained from the appropriate environmental conditions. The minimum rescue boat speed allowed is 3 knots.

Whenever the man is found by either the ship or the boat the next event in the scenario is the maneuvering of the vessel near the man. It is assumed that in the cases where the man was not seen falling overboard, the MOB is first seen again at or near the maximum distance of visibility. The vessel must proceed to the man at its best speed and come to a favorable heading and stop close to the man. The time for the ship to maneuver near the MOB, T_{MN}, is assumed to be normally distributed with a mean of two minutes, a standard deviation of one minute and a minimum value of zero. When the MOB is found by the ship, the ship has the option of attempting to recover him over the side or to use the rescue boat. Whether the simulated recovery is attempted by the ship or the boat is determined by the probability that the recovery will be by the ship, P_{10}. This probability is a function of ship type and is assigned a relatively high value of 0.50 for tugs and fishboats which are easily maneuvered and have low freeboard, and relatively low values of 0.05 for large, cumbersome ship types such as tankers and containerships.

If recovery by the ship is simulated, then the probability that the recovery is successful, P_{11}, determines whether the MOB is saved or not. This probability is assumed to be 0.80.

If recovery by the boat is simulated, then the next event in the scenario is the launching of the rescue boat unless, of course, the search was being conducted by both the ship and the boat in which case the rescue boat is considered to have already been launched. In the latter case, the boat must proceed to the

location where the ship has located the MOB. If the man is discovered on the first search pass, the distance between the ship and boat is equal to the elapsed time of the search multiplied by the difference in speeds. If the MOB is found on the first search pass by the ship, the elapsed time would be T_M. The time for the boat to proceed to the MOB's position, T_B, is therefore

$$T_B = |V_S - V_B| \cdot T_M / V_B$$

The maximum distance that the boat and ship will be apart on subsequent search passes will be the length of the search path equivalent to T_{LS} time units but on the average, when the ship finds the MOB, the rescue boat will be one fourth the length of the search path away. Thus, the mean time for the boat to proceed to the MOB's position unless their relative speeds keep them closer will be:

$$T_B = 0.25(V_S/V_B)T_{LS}$$

The modeling for the subsequent boat launch follows the discussion previously given. Note that this overall time duration is determined as a *function of the time to prepare for launch*, the ship's freeboard, the rescue boat system's descent speed, and the time required to release the falls.

The next event in the scenario, no matter what the search mode was, is for the boat to maneuver alongside the MOB. This is the single most important task that the rescue boat has to perform in the man overboard evolution. To provide a measure of the time required for a particular boat to perform this task, the concept of a "standard maneuver for rescue boats" has been developed. A boat's rated time to perform the standard maneuver, T_{SM}, is used in the MOBCSM model to determine the simulated time to manuever the rescue boat to the MOB.

The "standard maneuver" is conceived as the maneuvers that a rescue boat would have to perform in going from the side of the ship to a position where it can take the MOB aboard. In the

standard maneuver, it is assumed that the ship is in a sea with a three foot significant wave height with its bow into the seas. The MOB is postulated to be 100 yards abeam of the ship and 50 yards forward of the beam. The "standard maneuver" requires the rescue boat to leave the side of the ship beneath the davits, proceed to the man, and orient itself in a favorable position for taking the man on board. The time that a particular boat requires to perform this "standard maneuver" can be considered a characteristic of the boat. It is a more meaningful measure of performance of a rescue boat than, for example, the boat's speed because it combines the boat's speed, seakeeping, maneuvering, and control characteristics. The standard maneuver time can be determined for a particular boat by testing it on a calibrated course. Criteria for certification of rescue boats could be established based on studies of its effect on the survival rate.

As used in the MOBCSM model, the task of maneuvering the boat to the MOB is defined in units of standard maneuvers. Thus, if all other conditions were the same but the boat had to travel 300 yards to get to the man, the boat would be considered to perform two standard maneuvers, or if all other conditions were the same but the sea was flat calm, the boat would perform 0.5 standard maneuvers and the time required would be half of that to perform a full standard maneuver. Thus, it is assumed that the time to maneuver the rescue boat to recover the MOB, T_{MB}, is normally distributed with a mean equal to T_{SM} and standard deviation equal to $0.5T_{SM}$.

The next event in the scenario is to recover the MOB from the water. It is assumed that if the boat can get to the man while he is still alive and afloat that it will successfully recover him from the water. The only uncertainty assumed by the model is the time it takes to get him into the boat. It is assumed that under standard conditions the mean time will be 0.5 minutes. However, if the boat has a high freeboard or if a portion of

the boat is covered so that part of the gunwale is not available to take the man in over the side at that point, then the recovery time will be longer. This recovery time is assumed to increase as the square of the excess freeboard over 2 feet. The degree to which the boat is covered is expressed as the ratio of the length of open gunwale to the total length of gunwale, ϕ . It is assumed that a moderate amount of cover has little effect on the time to recover the man but that if the boat is almost totally covered with very small openings at the gunwale to bring the man aboard, the procedure will be slowed; this assumption is modeled using an exponential factor. Thus, the mean time to recover the MOB from the water, T_R, is obtained using the following expression:

$$T_R = 0.5\{1+\frac{(FB-2)^2}{4}\}(1+e^{4-10\phi}) \quad \text{if } FB > 2.0'$$

$$T_R = 0.5(1+e^{4-10\phi}) \quad \text{if } FB \leq 2.0'$$

The next event modeled is for the rescue boat to return to the ship with the MOB. The time to accomplish this is assumed identical to the time for the rescue boat to maneuver to recover the MOB.

Once alongside the ship, the option exists to attempt to hoist the boat aboard the ship with the crew and survivor aboard the boat or to attempt to transfer the survivor and/or crew to the ship before attempting to recover or abandon the boat. Whether the captain elects to attempt to recover the boat with its occupants depends upon the confidence he has in the recovery system. If the recovery system is good, for example, as is the tensioned falls system on current Coast Guard cutters, it is considered safer to bring the people aboard in the boat, On the other hand, conventional lifeboat davits are considered too risky to attempt recovery of the boat in high sea states so it is considered safer to have the crew and survivor climb from boat to ship via Jacobs ladders, cargo nets, etc.

In the current version of the model, the boat recovery system is tested on every simulation by setting the probability of disembarking the MOB and rescue boat crew, P_{13}, to 0.0. Advocates of single fall davit systems cite the ease with which the boat can be recovered in high sea states vis-a-vis the double fall davit systems. In the MOBCSM it is assumed that a double fall system has a 1% lower probability of a successful recovery exclusive of sea state effects. It is further assumed that the rate of degradation in the probability of a successful recovery with a single fall system is 0.016 per foot of wave height and that the rate of degradation is 5% greater with double fall systems. With these assumptions the probability of a successful recovery of the rescue boat, P_{15}, is determined using the following expression:

$$P_{15} = P_{15}'' \{1-0.01(N_F-1)\}-0.016\{1-0.05(N_F-1)\}h_w$$

where

P_{15}'' is the probability of successful recovery with single falls in a calm sea, and

N_F is the number of falls.

4.2 The Abandon Ship Model

The Abandon Ship Model is intended to describe a realistic profile of abandon ship situations to enable the effectiveness of alternative rescue system configurations to be studied. The focus of the model is on the action of the rescue boat in rescuing the people who abandon ship by entering the water. The success of the rescue boat in performing this task depends upon the survival time of the people in the water, the probability that the boat actually gets successfully launched, and the time for the boat to get to the people in the water.

The Abandon Ship Profile is described using a conventional block diagram format; this diagram forms the basis for a computer simulation and is consequently referred to as the Abandon Ship Computer Simulation Model (ASCSM).

Important characteristics of a ship abandonment, such as the number of people who enter the water and the probability of successful launch of the rescue boat, are dependent upon the characteristics of both the ship and the casualty. The ASCSM model has therefore been designed so that studies of abandonments can be made for a given ship type involved in different casualties with the ship equipped with a rescue boat or boats of specified characteristics.

The characteristics (relevent to the ASCSM model) of a representative vessel for each ship type are built into the model. If the study of the performance of the rescue boat with some variation of the ship's characteristics is desired, it is possible to override the stored characteristics.

Similarly, the relevent characteristics of the nine casualty types are built into the model. These characteristics can also be overridden if the performance of the rescue boat with casualties of, say, greater severity than those that the stored characteristics describe need to be studied.

NOMENCLATURE

ABANDON SHIP MODEL

Symbol	Description
C	% Of Crew Isolated From Lifeboats By Casualty.
C_{LB}	Capacity of Life Boat.
C_{LR}	Capacity of Liferaft
C_{RB}	Capacity of Rescue Boat.
CR	% Of Crew Killed Directly By Casualty
EXC	Total Excess Capacity In Lifeboats And Liferafts Which Get Launched.
i	Index No. Of Crewman Being Rescued From Water.
h_W	Significant Wave Height.
J	No. Of Crewmen Who Cannot Find Room In A Lifeboat Or Liferaft.
L	% Of Lifeboats Damaged By Casualty.
L_D	Length Of Collision Damage, Feet.
L_{LB}	Length Of Lifeboat, Feet.
L_{LR}	Length Of Liferaft, Feet.
N	Number Of Crewmen in Water.
N_{AS}	Number Of Crewmen Who Abandon Ship In Lifeboats Or Liferafts.
N_{BD}	Number Of Boats (Either Lifeboats Or Rescue Boat) Which Are Damaged Directly By Casualty.
N_{CR}	Number Of Crewmen.
N_{CRI}	Number Of Crewmen Isolated From Lifeboats By Casualty.
N_{CRT}	Number of Crewmen Killed Directly By Casualty.
N_K	No. Of Crewmen Knocked Overboard By Casualty.
N_L	No. Of Lifeboats Available For Use In Abandoning Ship.

Symbol	Description
N_{LB}	No. Of Lifeboats On Ship.
N_{LH}	No. Of Lifeboats Available On High Side Of Ship (& No. Successfully Launched).
N_{LL}	No. Of Lifeboats Available On Low Side Of Ship (& No. Successfully Launched).
N_{LR}	No. Of Liferafts On Ship.
N_{R}	No. Of Liferafts Available (& No. Successfully Launched).
N_{RB}	No. Of Rescue Boats.
N_{RBC}	No. Of Rescue Boat Crew.
N_{S}	No. Of Crewmen Rescued From Water By Rescue Boat.
N_{SIM}	No. Of Simulations.
N_{RBRB}	No. Of Crewmen Not Rescued By The Rescue Boat (May Be Rescued By Other Means).
P_1	Probability Casualty Is A Fire.
P_2	Probability Casualty Is A Collision
P_3	Probability Collision Results In A Fire.
P_4	Probability Casualty Is An Explosion.
P_5	Probability Explosion Results In A Fire.
P_6	Probability Casualty Is A Structural Failure.
P_7	Probability Casualty Is A Grounding.
P_8	Probability Lifeboat Damaged By Collision.
P_9	Probability High Side Lifeboat(s) is (are) Successfully Launched.
P_{10}	Probability Low Side Lifeboat(s) is (are) Successfully Launched.
P_{11}	Probability Liferafts(s) is (are) Successfully Launched.
P_{12}	Probability Rescue Boat Is Successfully Launched.
P_{13}	Probability Rescue Boat Is One Of Boats Damaged By Casualty.
P_{14}	Probability Rescue Vessel Is Near.

Symbol	Description
P_{CRF}	Probability Crewmen Isolated By Casualty Is Wearing PFD.
P_{KF}	Probability Crewman Knocked In Water Is Wearing PFD.
P_K	Probability Man Being Rescued Is One Who Was Knocked In Water.
R_I	Total Capacity Of Lifeboats Successfully Launched.
R_2	Total Capacity Of Liferafts Successfully Launched.
S	No. Of Survivors Rescued From Water In The Rescue Boat At A Given Time.
SL	Ship Length, Feet.
T_C	Time From Initiation Of Casualty To Order Given To Abandon Ship.
T_{HYP}	Time To Die From Hypothermia.
T_{IW}	Time A Particular Man Has Been In Water When Rescue Boat Reaches Him.
T_L	Time Rescue Boat Crew Arriving At Rescue Boat To Start Rescue Of Men In Water.
TOY	Time Of Year As % Of Time Between Mid-Summer & Mid-Winter.
T_{PU}	Cumulative Time To Pick Up Men In Water.
T_{RPT}	Time For Rescue Boat Crew To Report To The Rescue Boat.
T_S	Time To Survive In Water.
T_{SF}	Time To Remain Afloat With Floatation.
T_{SM}	Time For Boat To Perform "Standard Maneuver".
T_{SNF}	Time To Remain Afloat Without Floatation.
T_{TR}	Time To Transfer Survivors From Rescue Boat To Lifeboat Or Liferaft.
t_w	Water Temperature.
W	No. Of Simulation Where Rescue Boat Has Been Able To Attempt Rescue Of All Crewmen In Water.
X	No. Of Simulations Where Rescue Boat Was Damaged By Casualty.

Symbol	Description
Y	No. Of Simulations Where Rescue Boat Launched Failed.
Z	No. Of Simulations Where Rescue Boat (And All Lifeboats and Liferafts) Is Filled To Capacity Before Launch.
ZZ	No. Of Simulations Where Rescue Boat Was Filled To Capacity Before all Crewmen Could Be Rescued.
θ	Heel Angle.
ΔT_{PU}	Time To Rescue One Man From Water.
ΔT_{TR}	Time To Transfer One Survivor From Rescue Boat To Lifeboat Or Liferaft.
μ	Mean Value, Generally, Or Sub-Scripted For Any Variable Above.
α	Modal Value, Generally, Or Sub-Scripted For Any Variable Above.

The ASCSM model consists of three main parts as shown in Figure 4-3. The first part, the casualty development, models the development of the casualty to define the condition of the ship and the people in the water at the time of abandonment. Note that this definition is predefined and sets conditions from which the abandonment process can be studied. The second, the ship abandonment, models the abandonment of the ship by lifeboats and liferafts and the launching of the rescue boat. It determines how much capacity is available in the boats, rafts, and rescue boat that are successfully launched. The last part, the rescue of people in the water models the performance of the rescue boat in rescuing the people in the water and transferring them into other rescue vessels, lifeboats, or liferafts.

4.2.1 Measure of Performance

The overall measure of performance of the ASCSM model is the "rescue rate", that is, the ratio of the number of persons rescued by the rescue boat or boats to the total number of people in the water. This is not intended to imply that all those not recovered by the rescue boat are lost, for they could be rescued from the water by other means: e.g., by lifeboats, liferafts, other rescue vessels, helicopters, etc. It does mean, however, that the capabilities of the rescue boat and its performance as modeled were inadequate to rescue those persons.

4.2.2 Ship Characteristics

The eight ship types modeled are: 1) tanker, 2) LNG ship, 3) containership, 4) tug, 5) fishboat, 6) LASH ship, 7) Great Lakes bulker, and 8) ferry. For each ship type a representative U.S. flag vessel was selected as the basis for the determination of the set of ship characteristics.

The ship characteristics germaine to the abandon ship modeling are: 1) number of people on board, 2) number of lifeboats, 3) their capacity, 4) number of liferafts, 5) their capacity, 6) ship

ABANDON SHIP MODEL

OVERVIEW

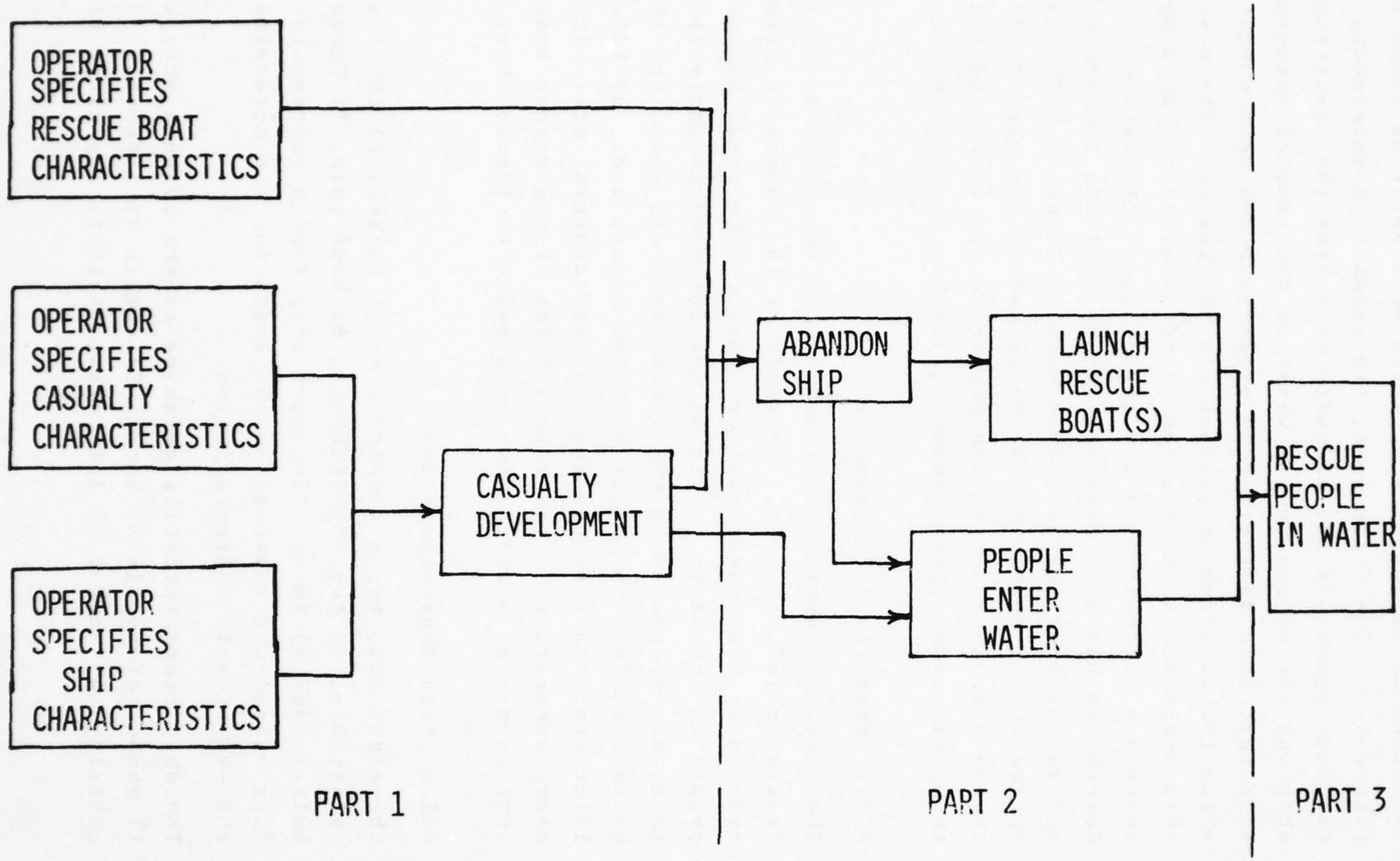


FIGURE 4-3

length, and 7) modal significant wave heights in mid-summer and mid-winter. The significance of most of these characteristics to an abandon ship simulation is self-evident; they will be discussed in the detailed description of the ASCSM model, however. The values of the characteristics for each of the eight ship types are listed in Table III. The numbers and capacities of lifeboats and liferafts are based on current U.S. Coast Guard Regulations, reference 8.

4.2.3 Casualty Characteristics

The first event in the scenario is the initiation of a ship casualty of the selected type. Of course, only a small percentage of ship casualties lead to abandonment but every casualty modeled in the ASCSM model is an abandonment case. Analysis of ship abandonment cases reveals that there are only three reasons for abandonment under duress. These are when the ship is on the verge of: 1) being engulfed by fire, 2) sinking, and 3) capsizing. (Other causes for abandonment, e.g., when a ship becomes hopelessly aground but is not in danger of sinking or capsizing would lead to a more controlled evolution and are therefore not considered the subject of the ASCSM model.)

Further analysis of casualty records provides a categorization of the types of casualties which can lead to abandonment. Fires, explosions, and collisions can lead to the vessel being engulfed in fire. Explosions, collisions, structural failures, founderings, and groundings can lead to the vessel sinking. Capsizing is considered a basic casualty without regard to the cause (i.e. loss of stability, cargo shifting, tripping, etc.) Thus, the nine casualty types available for study in the ASCSM model are:

1. Fire
2. Explosion and fire
3. Explosion and sinking
4. Collision and fire
5. Collision and sinking

TABLE III: STANDARD SHIP CHARACTERISTICS

	Tanker	Containership	LNG	Fishboat	Tug	Barge Carrier (LASH)	Great Lakes Bulker	Ferry	
Characteristics/Ship Number	1	2	3	4	5	6	7	8	UNITS
Ship Length	845	710	900	75	150	740	708	150	Feet
POB Ship	40	40	50	5	10	45	33	200	---
No. of Lifeboats	4	2	4	0	0	2	2	0	---
Capacity of Each L.B.	33	40	33	0	0	50	40	10	---
No. of Liferafts	1	1	2	1	1	1	2	8	---
Capacity of Each L.R.	25	25	25	10	10	25	10	25	---
Mode of Sign. Wave Hgts.--Mid-Winter	6.5	5	5	5	5	5	4	5	Feet
Mode of Sign. Wave Hgts.--Mid-Summer	3	3	3	3	3	3	2	3	Feet
Mean Water Temp.--Mid-Winter	38	38	38	38	38	38	42	38	Deg. F.
Mean Water Temp.--Mid-Summer	70	70	70	70	70	70	70	70	Deg. F.
Prob. Rescue Vessel Nearby	.2	.3	.25	.75	.8	.3	.4	.8	---

6. Structural Failure (with sinking)
7. Grounding (with sinking)
8. Foundering (with sinking)
9. Capsizing

The development of the casualty leads to a number of things happening which have more or less significance to the rescue boat's task of rescuing survivors from the water. Some of the people may be killed as a result of the casualty and therefore be eliminated as possible survivors, either in the water or otherwise. Some people may be knocked overboard as a result of the casualty such as in an explosion or collision. Some people may be isolated as a result of the casualty and not be able to abandon ship by lifeboat or liferaft. For example in a structural failure or explosion which results in the ship being broken in two, the bow lookout and others may be left on the bow section of the ship where there is no lifeboat or liferaft. Lifeboats, liferafts, and the rescue boat may be damaged by the fire, explosion, or collision. During sinking and capsizing the ship will develop a heel angle to one side. Finally, the casualty will take some time to develop to the point where it is decided to abandon ship. Except for damage to boats in a collision, the likelihood of each of these events is assumed to be normally distributed with the mean value assigned as a casualty type characteristic. For example, the mean time for a collision and fire to develop into an abandon ship situation is assumed to be 30 minutes while a capsizing is assumed to develop into an abandon ship situation in an average time of five minutes. The mean value for each of these casualty characteristics for each casualty type are preassigned. The standard deviation of each of the normally distributed characteristics is assumed to be half the mean; the minimum values are assumed zero and the maximum values are postulated to be twice the mean. The values of the characteristics of each casualty type are given in Table IV.

The probability that a boat will be damaged in a collision can be calculated as a function of the ship and casualty characteristics. Research on collision damage (reference 9) provides some

TABLE IV: CASUALTY CHARACTERISTICS

	Fire	Collision & Fire	Collision & Sinking	Explosion & Fire	Explosion & Sinking	Structural Failure	Grounding	Capsizing	Foundering	
Characteristics/Casualty Number	1	2	3	4	5	6	7	8	9	UNITS
Mean Fraction of POB Killed	.05	.02	.02	.1	.1	0	0	.1	0	---
Mean No. of POB Knocked Overboard	0	.5	.5	1	1	0	0	2	0	---
Mean Fraction of POB Isolated	.05	.05	0	.05	.05	.05	0	0	0	---
Mean Fraction of Lifeboats Destroyed	.1	.1	0	.1	.1	0	0	0	0	---
Mean Length of Damage	0	20	20	0	0	0	0	0	0	Feet
Mean Heel Angle	0	0	20	0	20	20	20	30	20	Degrees
Mean Time for Casualty To Develop	30	30	30	5	20	15	20	5	20	Minutes

insight into the location and extent of collision damage to the striken ship. It is assumed in the ASCSM model, based on Varges' discussion of reference 9, that the ramming vessel is never damaged so seriously as to require abandonment. Figure 4-4 of reference 2 shows that the probability of damage length has a mode of 20 feet. For the purpose of the ASCSM model it was assumed sufficient to approximate Figure 4-4 with a normal distribution with a mean of 20 feet, a standard deviation of 10 feet, a minimum of zero and a maximum of 40 feet. Figure 4-10 of reference 9 shows that the distribution of damage within the vessel's length is concentrated somewhat toward the forward part of the ship with the most frequent occurrence at amidship. For simplicity in the ASCSM model, the data of Figure 4-10 was approximated by a uniform distribution from bow to stern. Again for simplicity, it was assumed that the location of a boat was equally probable anywhere along the length of the ship. Under these assumptions, then, the probability that the collision damage will coincide with a boat's position is computed as the ratio of the sum of the total length of boats on one side of the ship and the length of collision damage to the length of the ship.

A review of the characteristics of a number of standard lifeboats shows that the boat length can be approximated reasonably well by the following relationship

$$L_{LB} = 7.0\sqrt[3]{C_{LB}}$$

where

L_{LB} is the lifeboat length in feet and

C_{LB} is the lifeboat capacity in number of people.

This is shown in Figure 4-4. The length of each lifeboat specified by the ship characteristics and the rescue boat is determined by this equation.

The probability that the collision occurs in way of a boat, P_8, is therefore expressed as:

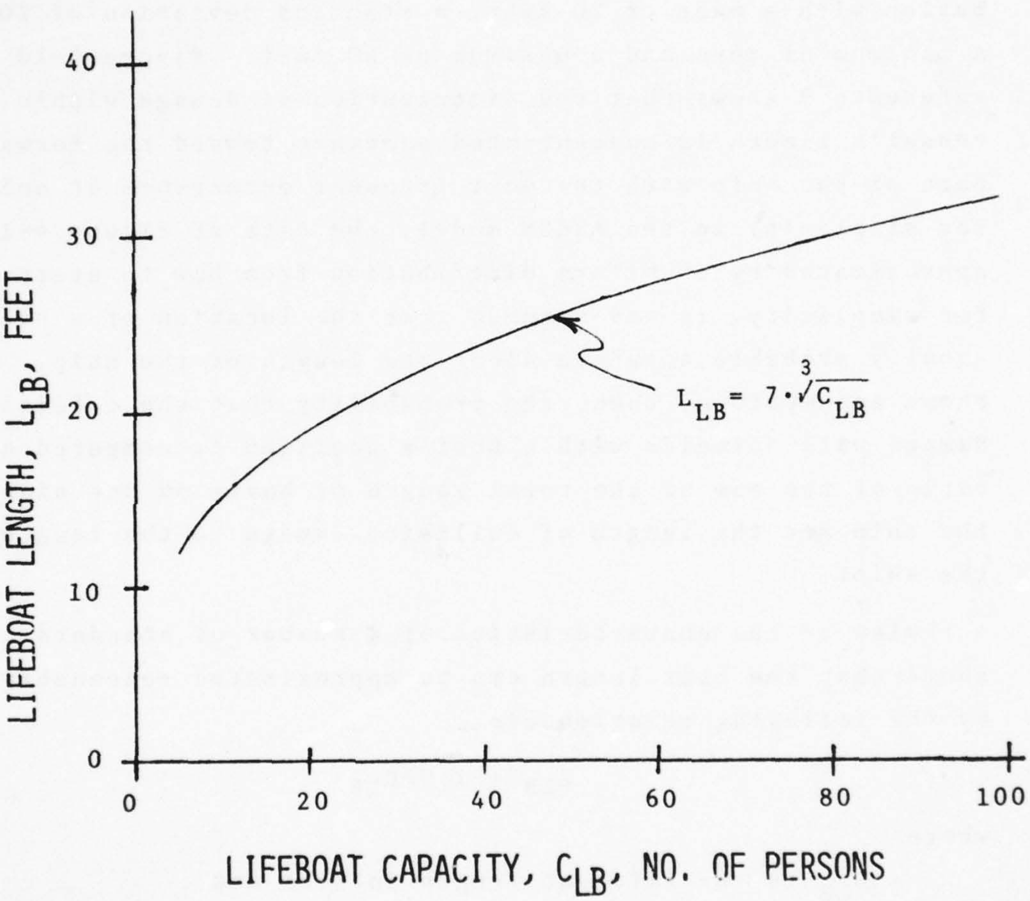


FIGURE 4-4. RELATIONSHIP BETWEEN LIFEBOAT LENGTH AND LIFEBOAT CAPACITY

SOURCE: TRANS. SNAME, 1961, P. 218

$$P_8 = \frac{N_{LB} \cdot L_{LB} + N_{RB} \cdot L_{RB} + L_C}{L_S}$$

where

N_{LB} is the number of lifeboats

N_{RB} is the number of rescue boats

L_{RB} is the length of each rescue boat, feet

L_S is the ship length, feet, and

L_C is the damage length, feet.

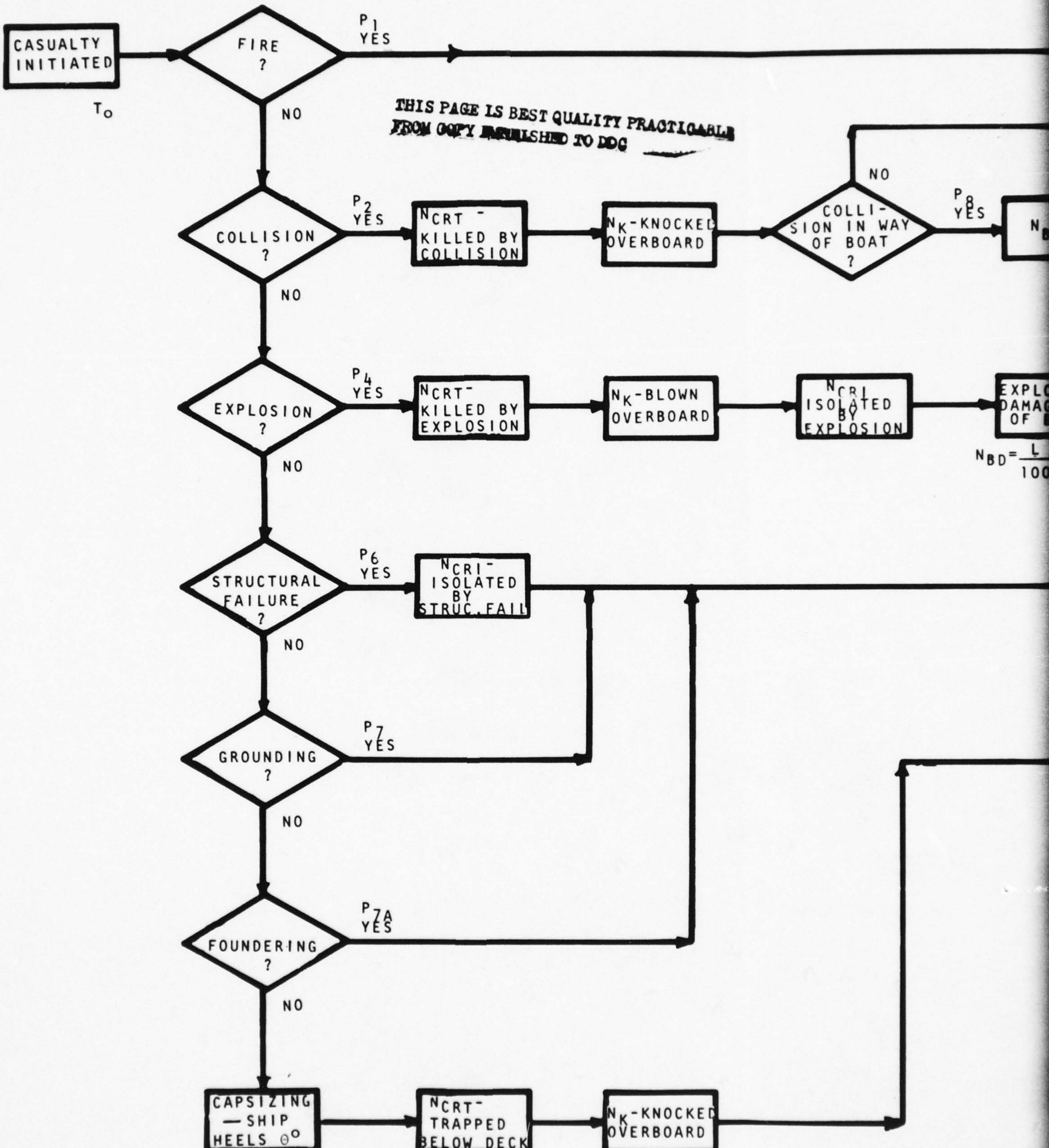
4.2.4 Detailed Description of ASCSM Model

A detailed diagram of the ASCSM model is shown in Figure 4-5a, b, and c. The three parts of the model: 1) casualty development, 2) ship abandonment, and 3) rescue of people in the water, are clearly evident.

In the casualty development section there are a number of possible paths to follow depending upon the values of probabilities P_1 through P_{7A}. In the present version of the model probability P_1 through P_{7A} can only take the values 1.0 or 0.0. For simulation purposes, these values are set in a matrix stored within the program according to the index number of the casualty type. The matrix is shown in Table V. Thus, when the casualty type is specified, the values of P_1 through P_{7A} are set as either 1.0 or 0.0.

The consequences of each casualty, in terms of number of people killed, N_{CRT}, the number knocked overboard, N_K, and isolated, N_{CRI}, number of boats damaged, N_{BD}, heel angle, Θ, and time for the casualty to develop to the point of abandonment, T_C, are determined along each path. The procedure used throughout the casualty development is to assume that each of the above consequences is normally distributed with a mean given by the casualty type/characteristic matrix and a standard deviation of half the mean.

The mean number of people killed directly by the casualty (in fires, collisions, explosions, and capsizings only) is expressed


CASUALTY INITIATED
T₀
FIRE ?
P1 YES
NO
COLLISION ?
P2 YES
NCRT - KILLED BY COLLISION
NK-KNOCKED OVERBOARD
COLLI-SION IN WAY OF BOAT ?
P8 YES
NO
EXPLOSION ?
P4 YES
NCRT- KILLED BY EXPLOSION
NK-BLOWN OVERBOARD
NCRI ISOLATED BY EXPLOSION
EXPLO DAMAG OF
NBD= L / 100
STRUCTURAL FAILURE ?
P6 YES
NCRI- ISOLATED BY STRUC. FAIL
GROUNDING ?
P7 YES
FOUNDERING ?
P7A YES
CAPSIZING — SHIP HEELS θ°
NCRT- TRAPPED BELOW DECK
NK-KNOCKED OVERBOARD

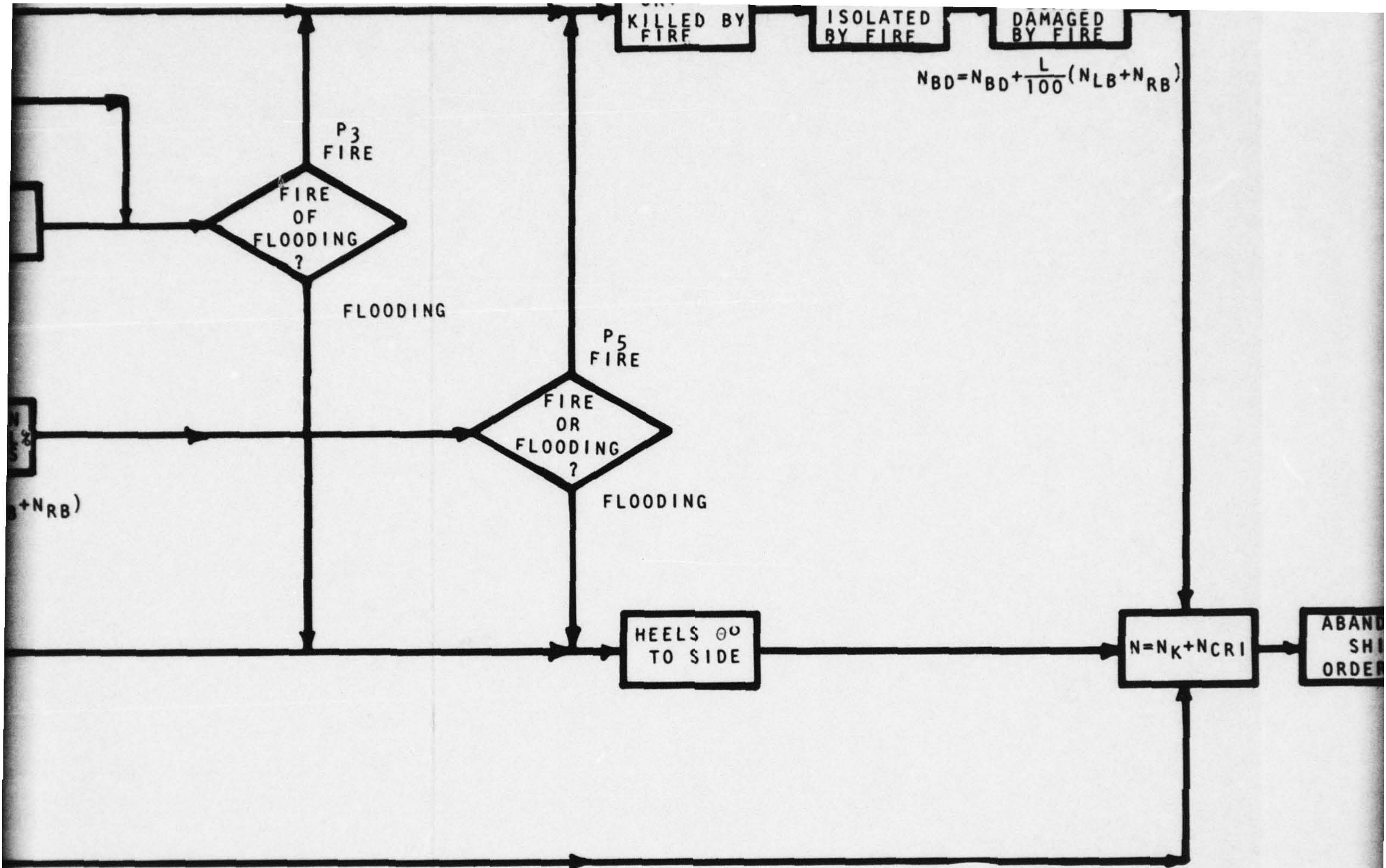
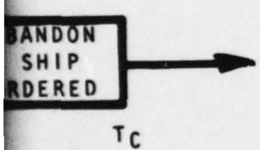


FIGURE 4-5A

ABANDON SHIP COMPUTER S

CASUALTY DEVELOPMEN



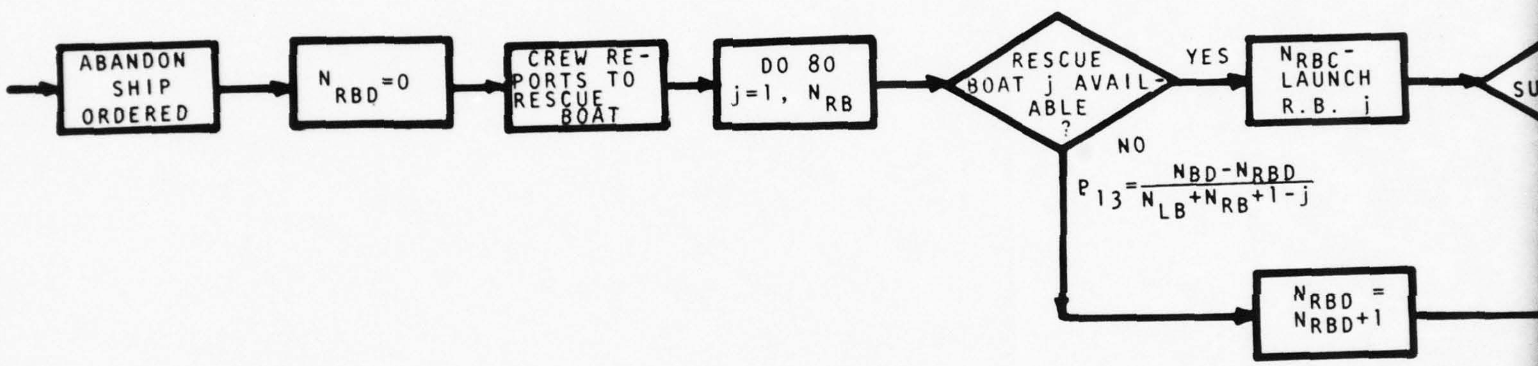
-5A

SIMULATION MODEL

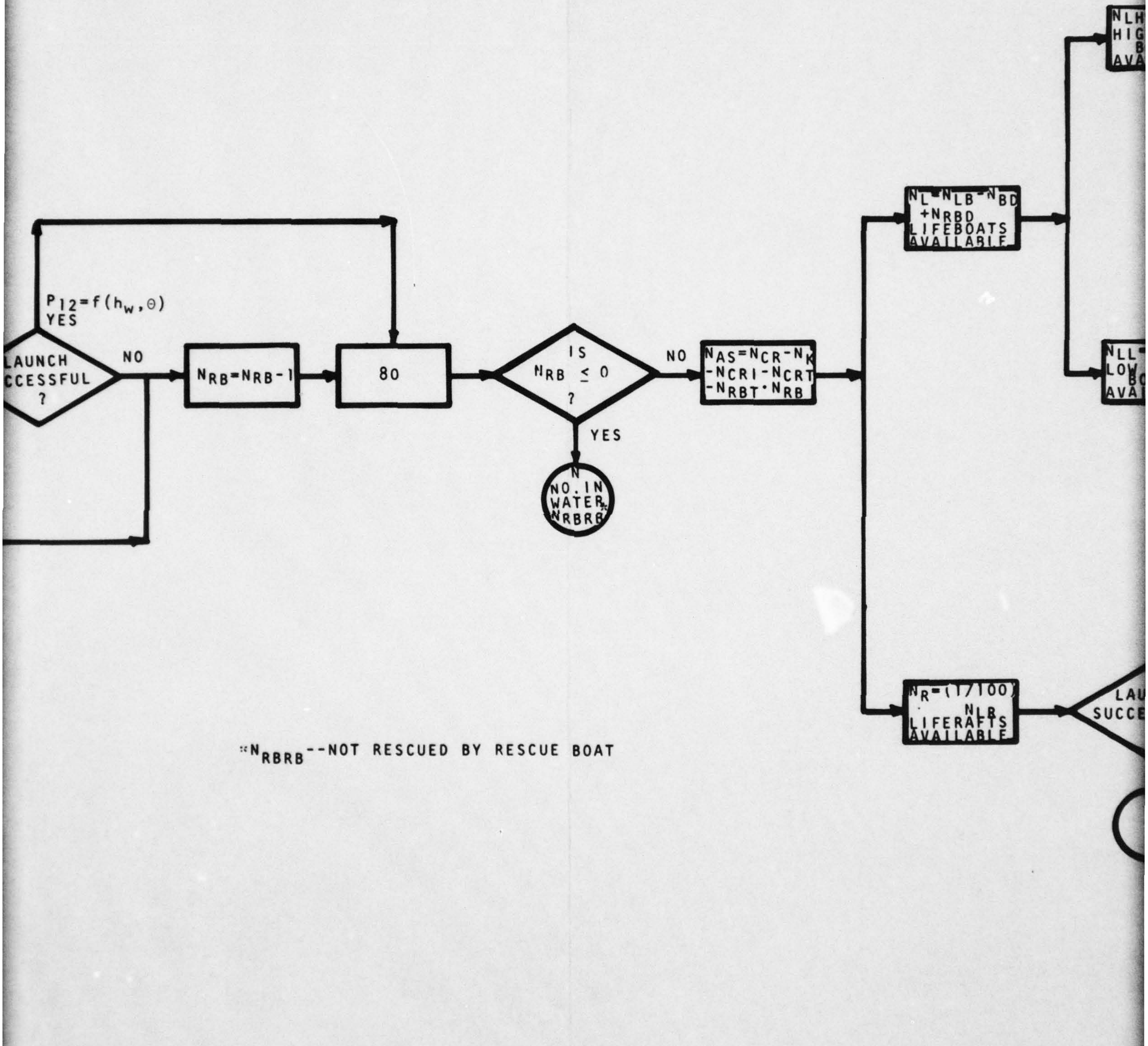
IENT SECTION

3

1



ABANDON SHIP ORDERED
$N_{RBD}=0$
CREW REPORTS TO RESCUE BOAT
DO 80 $j=1,\ N_{RB}$
RESCUE BOAT j AVAILABLE ?
YES
N_{RBC}- LAUNCH R.B. j
NO
$P_{13}=\frac{N_{BD}-N_{RBD}}{N_{LB}+N_{RB}+1-j}$
$N_{RBD}=N_{RBD}+1$



*N_{RBRB}--NOT RESCUED BY RESCUE BOAT

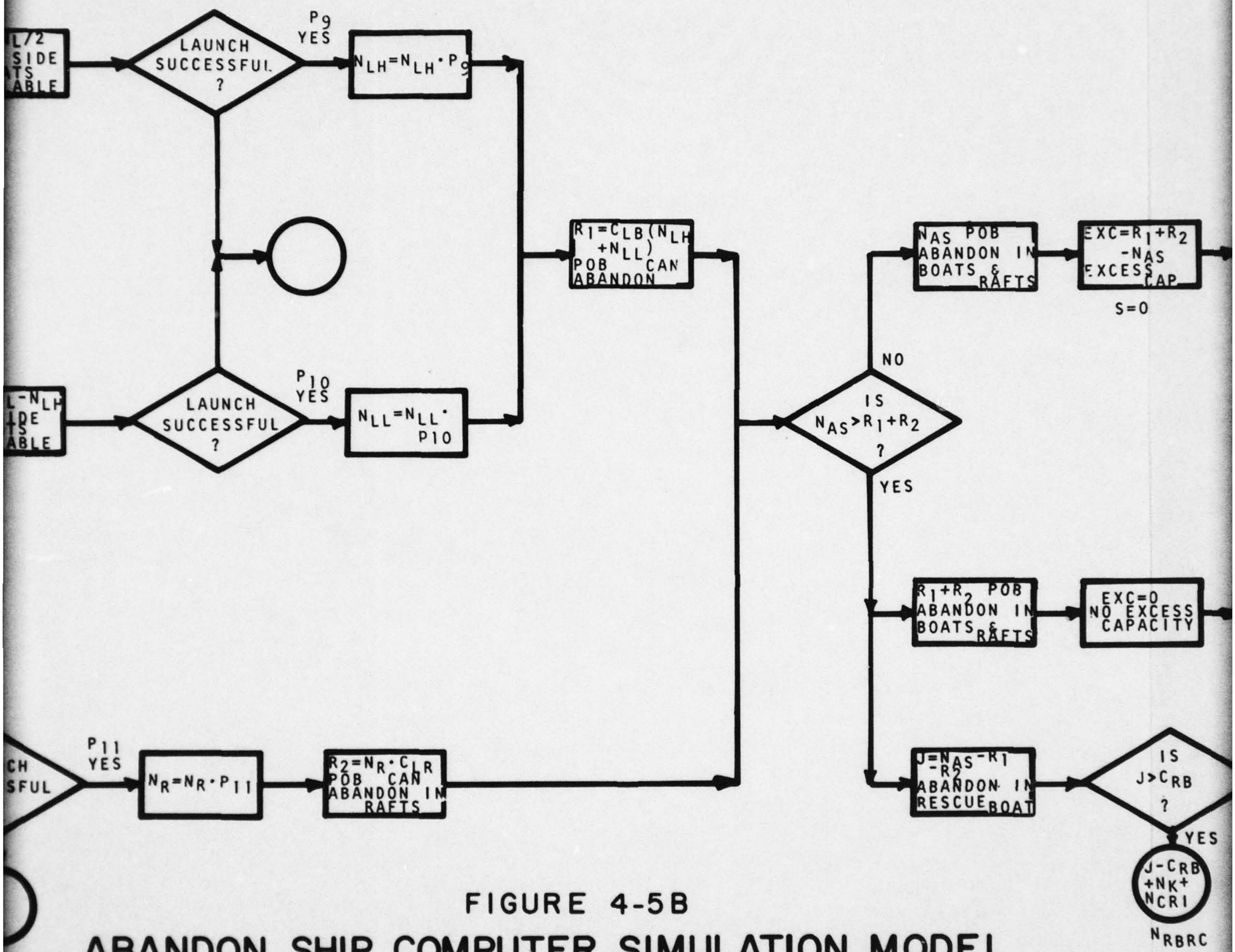
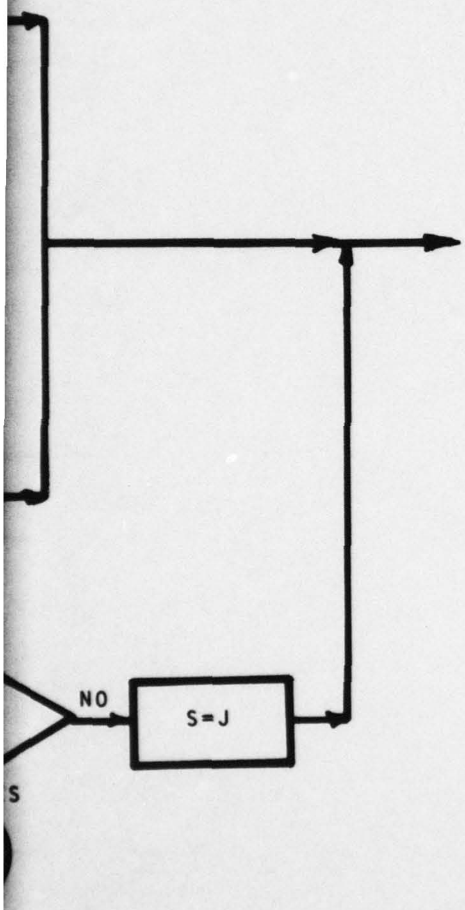


FIGURE 4-5B

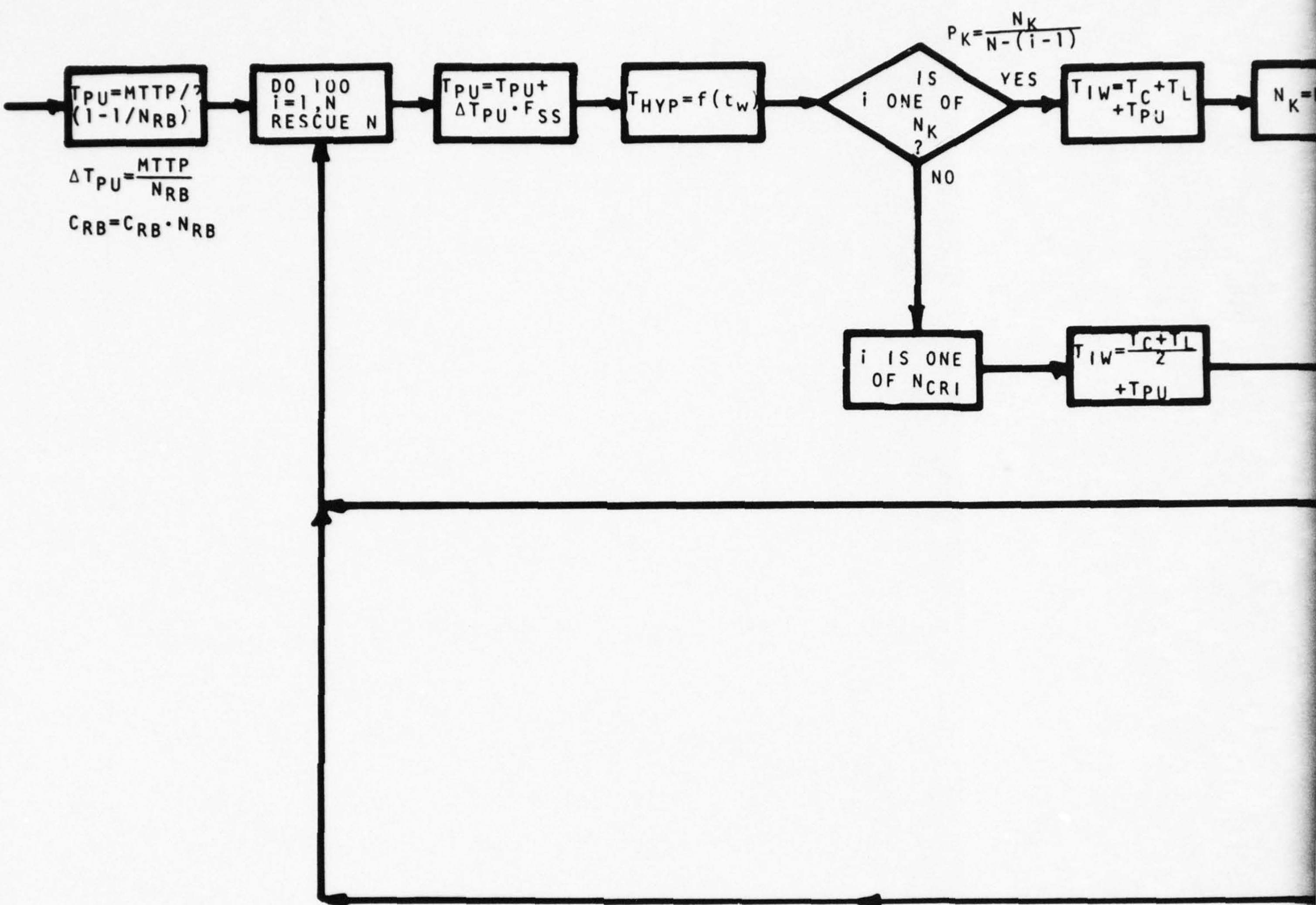
ABANDON SHIP COMPUTER SIMULATION MODEL

SHIP ABANDONMENT SECTION

3



4



TPU=MTTP/?
(1-1/NRB)
ΔTPU=MTTP/NRB
CRB=CRB·NRB
DO 100
i=1,N
RESCUE N
TPU=TPU+
ΔTPU·FSS
THYP=f(tw)
PK=NK/(N-(i-1))
IS
i ONE OF
NK
?
YES
NO
TIW=TC+TL
+TPU
NK=
i IS ONE
OF NCRI
TIW=(TC+TL)/2
+TPU

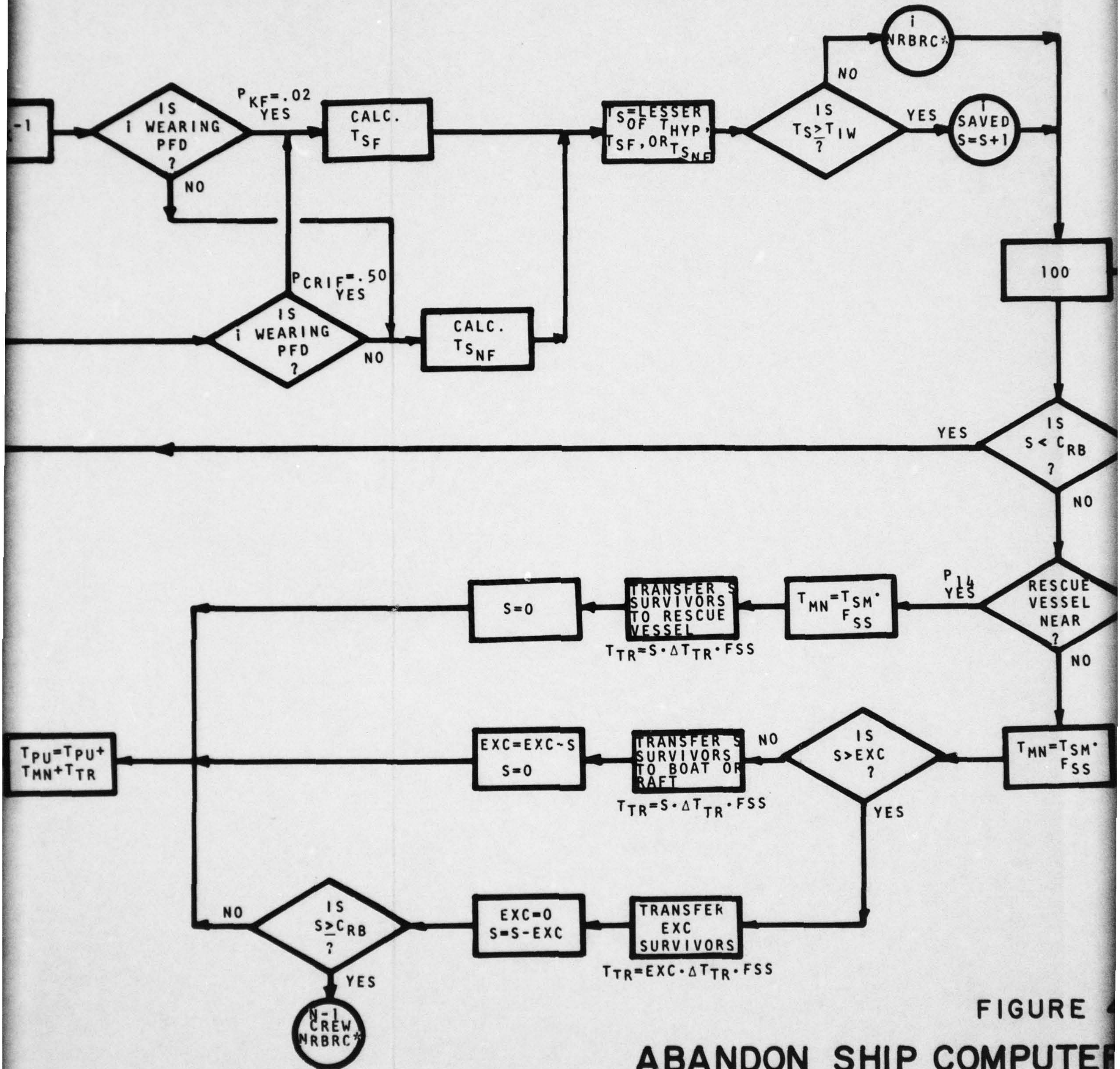


FIGURE 4

ABANDON SHIP COMPUTER

RESCUE OF PEOPLE IN

2

-5C

SIMULATION MODEL

THE WATER SECTION

3

TABLE V

PROBABILITY MATRIX FOR CASUALTY DEVELOPMENT SECTION
ABANDON SHIP COMPUTER SIMULATION MODEL

CASUALTY	PROBABILITIES							
	P_1	P_2	P_3	P_4	P_5	P_6	P_7	P_{7A}
Fire	1	0	0	0	0	0	0	0
Collision w. Fire	0	1	1	0	0	0	0	0
Collision w. Flooding	0	1	0	0	0	0	0	0
Structural Failure	0	0	0	0	0	1	0	0
Grounding	0	0	0	0	0	0	1	0
Capsizing	0	0	0	0	0	0	0	0
Explosion & Fire	0	0	0	1	1	0	0	0
Explosion w. Flooding	0	0	0	1	0	0	0	0
Foundering	0	0	0	0	0	0	0	1

as a percent of the number of people on board. The percent killed in a given simulation is determined as a random variable which is then converted to a fraction and multiplied by the crew size specified by the ship characteristics. The product is rounded-up to obtain integer numbers of people killed in each simulation, N_{CRT}. The number of people isolated from lifeboats and liferafts, N_{CRI}, (in fires, explosions, and structural failures, only) is determined in exactly the same way.

People being knocked overboard by explosions, collisions, and capsizings, N_K, are limited to those people who happen to be in an exposed position on deck near the casualty and is therefore less a function of total ship size. Thus, mean values of people knocked overboard are expressed in terms of individuals rather than a percent of the crew and the random variable generated is rounded-up to obtain an integer number of people.

Lifeboats, liferafts, and rescue boats are assumed to be subject to damage by fires, explosions, and collisions. The probability of a boat being damaged in a collision has already been discussed. The probability of boats and rafts being damaged by fire or explosion is expressed as a percent of the total number of boats, L. This value, which is a generated random variable, is multiplied by the total number of boats. This value is rounded-up to obtain integer numbers of boats damaged. The value of "L" is usually so low that either none, or at most one, boat is ever damaged. (A damaged boat is defined as one that cannot be used.) In compound casualties, such as an explosion and fire, the possibility of boat damage can occur due to both aspects of the casualty.

It is assumed that all of the people who are isolated from the lifeboats and liferafts by the casualty will have to abandon ship by jumping in the water. It is further assumed that no other persons, except those knocked or blown overboard by the casualty enter the water. Thus, the total number of people in the water, N, in a given casualty is given by the expression:

$$N = N_K + N_{CRI}$$

The purpose of the ship abandonment section of the ASCSM is to determine for each modeling:

1) whether the rescue boat or boats get successfully launched,
2) how many of the people on board abandon ship successfully in lifeboats and liferafts,
3) how much excess capacity is in the boats and rafts that do get launched successfully, and
4) how much capacity of the rescue boat is used at the time it is launched.

The first sequence of "events" of the ship abandonment section of the model is to determine the number of rescue boats successfully launched. If more than one rescue boat is carried, each boat is considered in turn. First, it is determined whether the rescue boat is one of the boats damaged by the casualty. It is assumed that all of the boats have an equal probability of being damaged. Thus the probability that the first rescue boat was one of the damaged boats is the ratio of the number of boats damaged to the total number of boats carried. The probability that succeeding rescue boats are the ones damaged is computed as the ratio of the number of remaining damaged boats to the total number of remaining boats. When the rescue boats are considered one at a time, in turn, the probability that any j^{th} boat is damaged, P_{13}, is determined as follows:

$$P_{13} = \frac{N_{BD}-N_{RBD}}{N_{LB}+N_{RB}-(j-1)}$$

where

N_{RBD} is the number of rescue boats determined to be damaged by consideration of the previous (j-1) rescue boats.

Attempts to launch those rescue boats not damaged are then permitted. The probability of a successful launch, P_{12}, in calm waters and without adverse heel affects, is assigned a fairly

high value consistent with the reliability of the launching system, say 0.999; this probability is assumed to be degraded by sea state and heel angle of the ship.

Current U.S. Coast Guard regulations (reference 8) specify the heel angle at which lifeboat davits must be fully operable. This angle is designated in the ASCSM model as the rated heel angle of the davits, Θ_R. It is assumed that there is no degradation in the probability of a successful launch, P_{12}, at all angles of heel of the ship, Θ, up to this value of Θ_R. It is readily appreciated that at increasing angles of list it becomes increasingly difficult to launch a boat from davits (at least conventional davits) on the high side of the ship simply because the boat will not fall free out of the chocks. On the low side of the ship, difficulty in launching a boat when the ship has a large angle of list is caused by the inability of the crewmen to operate the gear from the steeply angled deck. It is assumed in the ASCSM model that there is some heel angle for both the high and low side boats at which the probability of a successful launch, P_{12}, becomes zero. In the present version of the ASCSM model, these are set at 30 degrees and 40 degrees, respectively. The probability, P_{12}, is assumed to vary linearly between its value at Θ_R and zero at the above angles as shown in Figure 4-6.

The rated heel angle of the davits, Θ_R, is a parameter that the U.S.C.G. could specify differently to possibly influence performance or that a manufacturer could use as a design goal to enhance his product. This parameter consequently, is considered in the modeling as a rescue boat system characteristic so that studies can be made of its effect on the rescue rate.

The probability of a successful launch, P_{12}, is dependent not only upon the capability of the davits to drop the boat but also on the ability of the boat to safely meet the water's surface and be dispatched from the ship. There are many complex factors involved which could not be modeled within the scope of

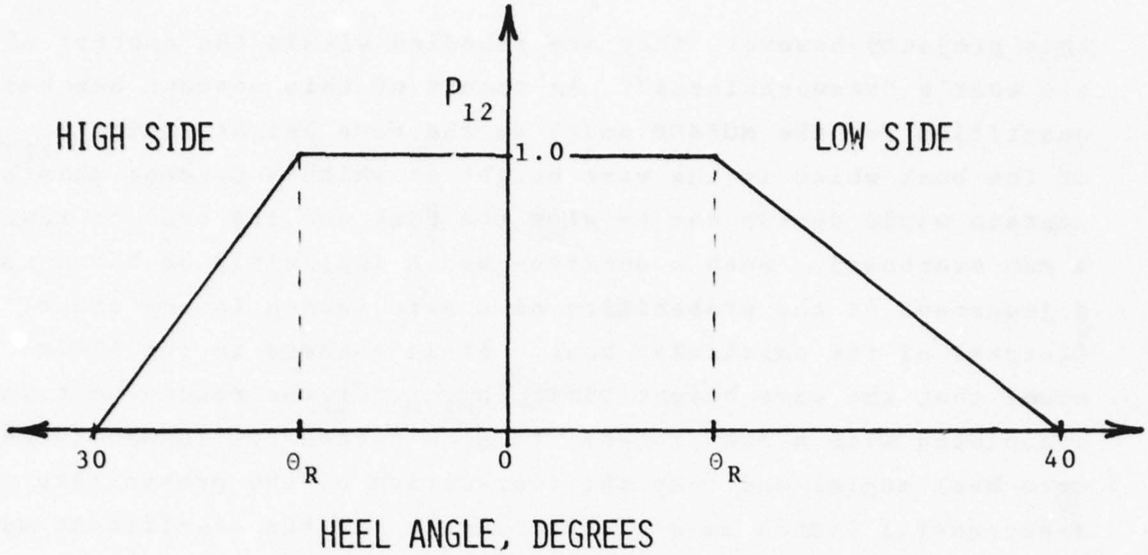


FIGURE 4-6. EFFECT OF HEEL ANGLE ON PROBABILITY OF SUCCESSFUL LAUNCH

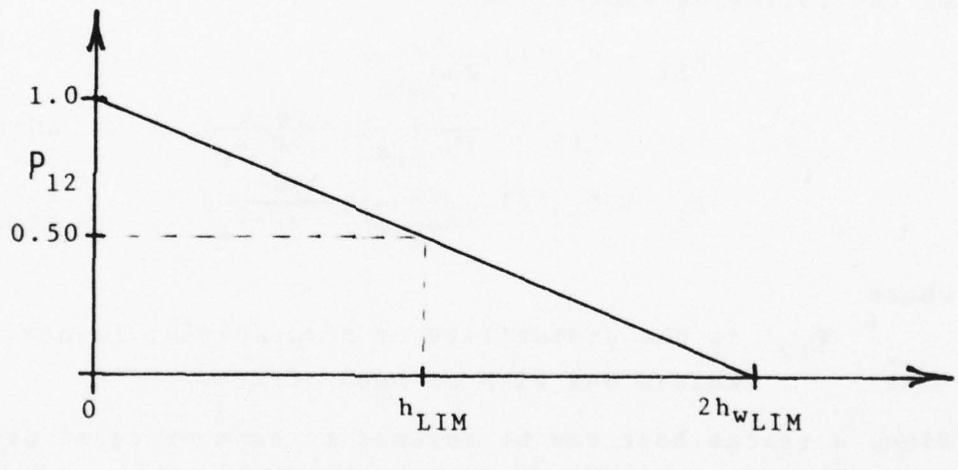


FIGURE 4-7. EFFECT OF SEA STATE ON PROBABILITY OF SUCCESSFUL LAUNCH

this project; however, they are embodied within the concept of the boat's "seaworthiness". An aspect of this concept has been quantified for the MOBSCM model as the wave height limit, $h_{w_{LIM}}$, of the boat which is the wave height at which a prudent ship's captain would decide not to risk the boat and its crew to rescue a man overboard. Such a decision would implicitly be based upon a judgement of the probability of a safe launch (among other factors) of the particular boat. It is assumed in the ASCSM model that the wave height limit, $h_{w_{LIM}}$, of the rescue boat is associated with a 50% probability of a successful launch (with zero heel angle) and that the degradation of the probability of a successful launch is a linear function of the significant wave height as shown in Figure 4-7.

The net probability of a successful launch is thus described by the following expressions:

$$P_{12} = P_{12}'\left(1-\frac{h_w}{2h_{w_{LIM}}}\right)$$

$$P_{12} = P_{12}'\left(1-\frac{h_w}{2h_{w_{LIM}}}\right)\left(\frac{40-\theta}{40-\theta_R}\right) \qquad 40\geq\theta>\theta_R \text{ low side boat}$$

$$P_{12} = P_{12}'\left(1-\frac{h_w}{2h_{w_{LIM}}}\right)\left(\frac{30-\theta}{30-\theta_R}\right) \qquad 30\geq\theta>\theta_R \text{ high side boat}$$

where

P_{12}' is the probability of a successful launch in calm waters and with no heel effect.

Since a rescue boat can be assumed to have an equal probability of being on the high or the low side, P_{12} for heel angles, θ, greater than θ_R can be taken as the mean between the last two equations above.

When the modeling determines that a rescue boat is either damaged or not launched successfully, the number of rescue boats, N_{RB}, is decreased by one. Whenever all of the rescue boats are damaged or fail in launch as determined by the model, i.e., when N_{RB} is

zero, the simulation is ended and the N people in the water are credited as "not rescued by the rescue boat", "NRBRB". This does not mean that they are "lost" since they may be rescued by other means but the ASCSM model is concerned primarily with the performance of the rescue boat.

The next "event" is to determine how many people attempt to abandon ship by lifeboat or liferaft, N_{AS}. It is assumed that everyone who can will want to abandon ship by lifeboat or liferaft. Those who cannot are those killed by the casualty, N_{CRT}, those isolated from the boats and rafts, N_{CRI}, those knocked in the water, N_K, and the rescue boat crew. No attempt has been made to describe the abandon ship situation under panic conditions. The number of people who attempt to abandon ship in lifeboats and liferafts, N_{AS}, is determined by:

$$N_{AS} = N_{CR} - N_K - N_{CRI} - N_{CRT} - N_{RBC} \cdot N_{RB}$$

where

N_{CR} is the number of people on board and

N_{RBC} is the number of rescue boat crewmen

The number of lifeboats available for abandoning ship, N_L, is the difference between the number of lifeboats carried, N_{LB}, and the number of lifeboats damaged. The number of lifeboats damaged is the difference between the total number of boats damaged, N_{BD}, and the number of rescue boats damaged, therefore, the number of lifeboats available, N_L, is determined by:

$$N_L = N_{LB} - (N_{BD} - N_{RBD})$$

The next issue is to determine whether the available lifeboats are on the high or the low side. It is assumed in the ASCSM model that if there are an even number of boats available, half are on each side. It is also assumed that the low side is likely to be the side where the casualty occurred and therefore it is more likely that any lifeboats which were damaged were on the low side; consequently if there is an odd number of lifeboats

available, it is assumed that there will be one more boat on the high side than the low side. Both of these assumptions are implemented by the pair of equations:

$$N_{LH} = \frac{N_L}{2}$$

and

$$N_{LL} = N_L - N_{LH}$$

where

N_{LH} is the number of available boats on the high side rounded up to an integer value, and

N_{LL} is the number of available lifeboats on the low side.

The probability of a successful launch of high side and low side lifeboats, P_9 and P_{10}, respectively, are determined according to the same method described earlier for determining the probability of a successful launch of the rescue boat except that the rated heel angle of the davits, Θ_R, is set at 15 degrees in accordance with current U.S.C.G. regulations, reference 8. The number of high and low side lifeboats actually launched is determined by multiplying the number of each category of lifeboats by their respective probabilities and rounding the answers up to integer numbers of boats. The aggregate capacity of all of the lifeboats which get successfully launched, R_1, is obtained by multiplying the capacity per boat by the total number of boats, thus:

$$R_1 = C_{LB} \cdot (N_{LL} + N_{LH})$$

Liferafts are assumed to be independently subjected to the same probability of damage due to the casualty as the boats. The number of liferafts available to abandon ship, N_R, is therefore obtained using the following expression:

$$N_R = (1 - \frac{L}{100}) \cdot N_{LR}$$

where

L is the percentage of lifeboats damaged.

The probability of a successful launch of a liferaft is assumed to be degraded due to the sea state effect but not due to heel angle. (Heel angle may even improve the launchability of certain types of inflatable life rafts.) The probability of successful launch of a liferaft, P_{11}, is therefore determined by

$$P_{11} = P_{11}'(1-\frac{hw}{40})$$

where

P_{11}' is the probability of a successful launch in calm water.

The aggregate capacity of the liferafts which get successfully launched, R_2, is obtained by multiplying the capacity per raft, C_{LR}, by the total number of rafts, N_R, thus:

$$R_2 = C_{LR} \cdot N_r$$

If the number of people attempting to abandon ship by lifeboat or liferaft, N_{AS}, is less than the capacity of the lifeboats, R_1, and liferafts, R_2, that are launched, then it is assumed that they all do so and the aggregate excess capacity in the boats and rafts, EXC, is determined as follows:

$$EXC = R_1+R_2-N_{AS}$$

If the capacity of the boats and rafts, R_1+R_2, is less than the number of people who attempt to abandon ship by boat or raft, N_{AS}, then it is assumed that the excess number of people, J, will attempt to abandon ship in the rescue boat or boats. This is computed as shown below:

$$J = N_{AS}-R_1-R_2$$

In cases where the number of people attempting to abandon ship via the rescue boat or boats, J, is greater than the aggregate capacity of the rescue boats, $N_{RB} \cdot C_{RB}$, then it is postulated that only the latter number of people can be so accommodated.

The excess number of people are assumed to be left aboard ship or assumed to enter the water. They and the N people who otherwise enter the water will have to be rescued by some other means; otherwise they will be lost. These people are categorized in the ASCSM model as "not rescued by the rescue boat" (NRBRB) and that particular simulation is then terminated.

In the cases where the number of people attempting to abandon ship via the rescue boat, J, is less than the aggregate capacity of the rescue boats, $N_{RB} \cdot C_{RB}$, then all of the J people are assumed to do so and the population of survivors in the rescue boats, S, is then set equal to J. This completes the ship abandonment section of the ASCSM model.

The "rescue of the people in the water" section of the model is designed such that each of the N individuals is rescued one at a time. This is intended to model the action of an actual boat in going from one to the next man sequentially. The rescue of each man is determined by comparing his total time in the water with his calculated survival time. If the rescue boat retrieves him from the water before his time to survive has expired, he is considered rescued; otherwise he is not.

The man's survival time is calculated as previously discussed; the shorter time of either his simulated survival time period due to hypothermia or his simulated time period to stay afloat with or without floatation is used.

The time interval before the effects from hypothermia are experienced is dependent upon the water temperature. The relationship used in the ASCSM model is the same one used in the MOBCSM model and has previously been described. Although the water temperature, and thus the mean time period for survival will be the same for each individual, the ASCSM model simulates a different time interval to die of hypothermia, T_{HYP}, for each individual by generating a new random variable for each from the distribution of T_{HYP}.

The man's time period in the water, T_{IW}, and his time frame to stay afloat, are both assumed to be a function of which class of people in the water he belongs to. If he was one who was knocked in the water by the explosion, collision, or capsizing, he is assumed to have entered the water when the casualty was intitated. His time in the water is therefore the sum of the time for the casualty to develop to the point of abandonment, T_C, plus the time to launch the rescue boat, plus the time for the boat to pick him up, T_{PU}, that is:

$$T_{IW} = T_C + T_L + T_{PU}$$

The other group of people in the water are those who are isolated from the lifeboats and liferafts by the casualty and therefore must enter the water in order to abandon ship. Their time spent in the water is more difficult to estimate. In the real world, and in the absence of panic, they would prefer to wait until a boat was standing by to retrieve them before jumping into the water. On the other hand the fact that they are isolated by the fire, explosion, or structural failure may be symptomatic of the casualty being more severe at their location thereby forcing an earlier abandonment. The ASCSM model deals with this uncertainty by assuming that these people enter the water, on the average, at the midpoint of the time period between the outbreak of the casualty and the launch of the rescue boat. The total time spent in the water, T_{IW}, for a man who was isolated by the casualty is calculated as follows:

$$T_{IW} = \left(\frac{T_C + T_L}{2}\right) + T_{PU}$$

In the modeling of the rescue boat's retrieval of people in the water, it was necessary to identify how each individual entered the water, i.e., to determine whether he was knocked in the water or if he was isolated from the lifeboats. It was then assumed that there did not exist a preferred ordering for the retrieval of the people by the rescue boat, i.e., that the rescue boat

would set about its task on an orderly, first arrival basis. Therefore, the probability of rescuing a person who was knocked overboard, P_K, was determined using the ratio of the number of people who were knocked overboard and who were still in the water, N_K, to the total number of persons still in the water. Thus when rescuing the i^{th} man, the probability was computed using the following:

$$P_K = \frac{N_K}{N-(i+1)}$$

Whenever the person being rescued is identified as one who was knocked overboard then the value of N_K is reduced by 1.

A similar procedure is used to determine the probability of rescuing a person who was isolated by the casualty and was subsequently forced to jump.

The distribution of time that a man can remain afloat is assumed to be dependent upon whether he has floatation or not and is identical to the distributions discussed in the MOBCSM model. Basically, they are assumed to be Rayleigh distributions with modes of 10 minutes without floatation and 30 minutes with floatation. The next task in the ASCSM model is therefore to determine whether the man being rescued has floatation or not.

It is assumed that the casualty was unexpected and therefore at the time it occurred the people on the ship were engaged in their normal business, that is, they were not wearing PFDs. Those who were knocked overboard because they were in exposed positions on deck in proximity to the explosion or collision are assumed to have a very low probability of having floatation, P_{KF}: assumed to be 0.02. On the other hand, those who were isolated from the lifeboats are assumed to have a reasonable chance of getting floatation before they are forced to enter the water. Their probability of having floatation, P_{CRIF}, is set at 50%.

The time frame over which the individual can stay afloat is modeled as described above; his survival time, T_S, is determined as the shorter time of this and the previously determined time period to survive hypothermia effects. If the time period of survival, T_S, is greater than the man's time spent in the water, T_{IW}, the model assumes that he is saved. If not, he is considered lost.

Whenever a man is saved, the population of the rescue boat, S, is increased by one. If S is less than the capacity of the rescue boat (or boats) the boat goes on to rescue the next man and continues this routine until either all the people in the water have received a rescue attempt or the boat capacity is reached.

The ASCSM model does not attempt to describe the dispersion of the people in the water so that the time to get from one man to the next can be determined as a function of their separation and the boat's speed. Instead, the model assumes that the people are dispersed with some average distance between them and that the boat's mean time to pick up a man, ΔT_{PU} or MTTP, which has been previously determined by tests, is an adequate measure of the boat's "agility" and consequently a measure of the time required to pick-up survivors. Here, "agility" is the integrated speed, maneuvering, control, seakeeping, and stability characteristics as applied during a typical rescue effort. The boat's agility characteristic, MTTP, as employed in the ASCSM model can be related to actual boat performance as determined on a calibrated course.

The sea state will obviously affect the boat's MTTP. The degree to which the wave height will increase the time for the boat to recover is also dependent upon the boat's seakeeping characteristics. It is assumed that the MTTP will be double its calm water value at the boat's wave height limit, $h_{w_{LIM}}$. Under the

assumption that the MTTP increases linearly with wave height, a sea state factor, F_{SS}, has been defined, as shown in Figure 4-7 which is then multiplied by the boat's rated value of MTTP (in calm water) to obtain the appropriate value of MTTP in the simulated sea state.

If after rescuing a man from the water, it is determined that the rescue boat's population, S, is equal to the boat's capacity, C_{RB}, it will be necessary to transfer some of the survivors out of the rescue boat before more can be rescued. The first preference would be to transfer them to a rescue vessel if one is near. The model postulates that the probability that a rescue vessel is near, P_{14}, is primarily a function of the ship type, e.g., tankers operate more often in remote areas than do tugs, fishboats, and ferries and would consequently have less likelihood of having a rescue vessel in the vicinity. The value of P_{14} is therefore assigned as a ship characteristic, except that in the case of a collision, regardless of the ship type, the colliding vessel is assumed never to need abandonment and is therefore available as a rescue vessel. Thus, in collision type casualties, P_{14} is always set at 0.95.

In the cases where a rescue vessel is determined to be near, the rescue boat is assumed to maneuver near the rescue vessel. The time required to perform this maneuver is postulated to be the time to perform the standard maneuver, T_{SM}, as defined for the MOBCSM model, multiplied by the sea state factor, F_{SS}. The rescue boat is then assumed to transfer its full capacity of survivors to the rescue vessel. It is assumed that the time to transfer all of the survivors, T_{TR}, is equal to the time to transfer one survivor, ΔT_{TR}, multiplied by the number of survivors, S, and the sea state factor, F_{SS}. After transferring all the survivors, the boat's population is reset to zero, the accumulated time to pick up survivors, T_{PU}, is incremented by the

time to maneuver alongside the rescue vessel, T_{MN}, and transfer the survivors, T_{TR}, and the boat is then presumed to continue its retrieval operation.

In cases where a rescue vessel is not near, the rescue boat is assumed to maneuver alongside the nearest lifeboat or liferaft with excess capacity. The time required to perform this maneuvering and discharging operation is computed as discussed above. If the number of survivors in the rescue boat, S, is less than the excess capacity in the lifeboat or liferaft, EXC, then all S survivors are transferred to the lifeboat or liferaft. The time required to effect the transfer is the same as in the case of transfer to rescue vessel, that is:

$$T_{TR} = S \cdot \Delta T_{TR} \cdot F_{SS}$$

The population of survivors in the rescue boat is reset to zero and the excess capacity of the lifeboats and liferafts is reduced by S.

If the number of survivors in the rescue boat, S, is greater than the excess capacity in the lifeboats and liferafts, EXC, then only EXC survivors can be transferred out of the rescue boat. The time to effect this transfer will be

$$T_{TR} = EXC \cdot \Delta T_{TR} \cdot F_{SS}$$

The excess capacity of the lifeboats and liferafts is set to zero and the population of survivors in the rescue boat is reduced by EXC. The rescue boat retrieval operation is modeled such that it then proceeds to the next man in the water after incrementing the time to pick up survivors, T_{PU}, by the time to maneuver alongside the lifeboat or liferaft, T_{MN}, and the time to transfer the survivors, T_{TR}.

In cases where there is no excess capacity in the lifeboats and liferafts, then the model assumes that no one can be transferred

out of the rescue boat. The remaining people in the water cannot be rescued by the rescue boat and must therefore be rescued by other means or be lost. The ASCSM model places these people in the category of "not rescued by the rescue boat", NRBRB.

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STUDY OF RESCUE BOAT PERFORMANCE FOR SELECTED COMMERCIAL VESSEL--ETC(U)
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5. COMPUTER SIMULATION

Two computer simulations were developed to perform effectiveness analyses of rescue boat characteristics: one simulating the man overboard casualty and the other ship abandonment. The simulations are of a statistical nature; this choice was necessary because of the large number of alternative events and the random nature of many of these events which produce a wide spectrum of scenarios in which rescue boats must perform. Analysis of rescue boat performance in a "typical" or "average" scenario could lead to misleading conclusions. Through the use of these similations, rescue boat performance can be analyzed in a properly weighted selection of elements of the scenario spectrum. Statistics of the simulated performance are more truly representative of long term performance of the rescue boat than the results of a deterministic analysis.

In both programs, the preparations to perform a simulation run are accomplished interactively between the analyst/operator and an "operator program". The "operator program" solicits, via a CRT display, values for the required input variables. The operator responds to the queries via the keyboard.

The operator program is structured for simplicity of use, to minimize input errors, and to provide a large degree of flexibility.

An overview of the overall simulation approach is depicted in Figure 5-1. The man overboard and abandon ship computer simulation programs are described in detail in the Programmer's Manual, Report No.CG-D-9-78. Detailed instructions for using each program are contained in the User's Manual, Report No.CG-D-8-78.

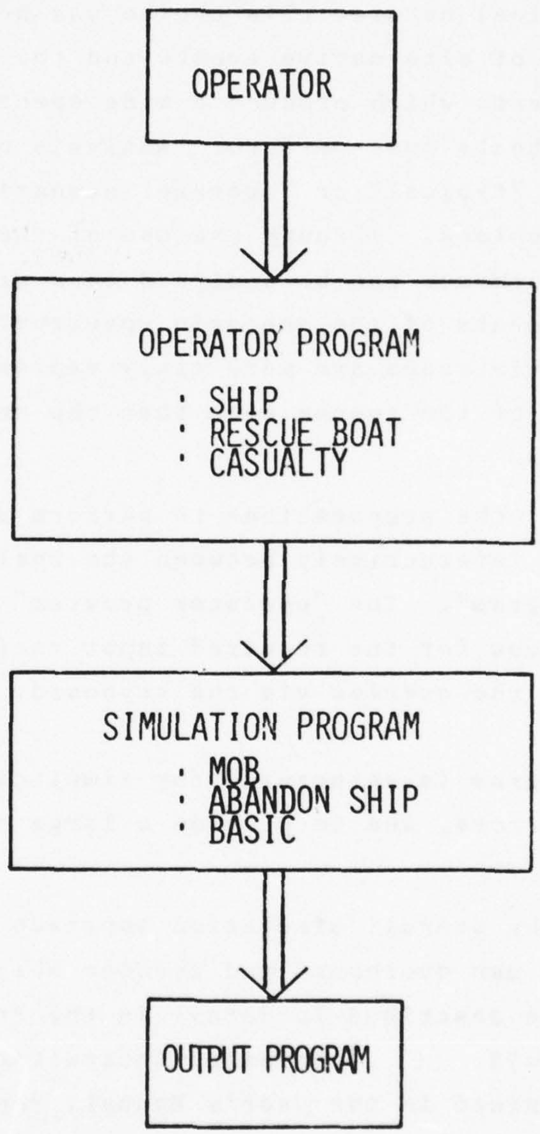

OPERATOR
OPERATOR PROGRAM
· SHIP
· RESCUE BOAT
· CASUALTY
SIMULATION PROGRAM
· MOB
· ABANDON SHIP
· BASIC
OUTPUT PROGRAM

FIGURE 5-1

Both the Man Overboard and the Abandon Ship Simulations are written specifically for the problem intended and are more compact than an equivalent general purpose simulation program. Both simulations were designed for use on the Wang 2200 System and of course, can be modified to run on most mini or microcomputer systems that have a BASIC capability. One of the primary motivations for writing the simulations for accomodation on a small computer was the cost savings involved. Since the simulations require a sufficient number of iterations for statiscal convergence, their use on a larger, more expensive computer could become prohibitive.

5.1 Man Overboard Computer Simulation Program, MOBCSM

The Man Overboard Computer Simulation Program consists of three distinct programs written in BASIC. The first program is used interactively by the analyst to obtain the information required to perform one or more simulations. This first program, the Opertor Program, provides an interactive input scenario to the Operator which asks for each piece of information required to complete the data set needed to perform a simulation run. The operator program prints a summary of the information collected and writes a disk file containing all the information required by the second program.

The second program, Simulation Program, gets its input from the disk file written by the Operator Program, performs the simulation specified, produces the reports requested by the user, and writes a disk file containing the input information and the results of the simulation performed.

The third program, the Output Program reads the disk file created by the Simulation program and produces a report.

5.2 Abandon Ship Program

The Abandon Ship Computer Simulation Program was also written in the BASIC computer language. This program has the ability to simulate a repetitive sequence of events as often as required by the dynamics of the program. This particular capability is required in the "Rescue of People in the Water" section of the model where the rescue event sequence is repeated for each of the j people in the water and there is no specified upper limit on the value of j.

The program which was written performs all of the functions required for the abandon ship model. Procedures for generating random variates from probability distributions are of course provided and include the Rayleigh distribution.

As in the man overboard model, input data is assembled for a simulation via an interactive exchange between the operator/analyst and an Operator Program. The operator enters the desired values of rescue boat characteristics and ship and casualty types in response to queries presented on a CRT display. Ordinarily, the ship and casualty characterisitics are set at standard values contained within the operator program unless the operator indicates (by response to the respective CRT query) a desire to override selected characteristics; in this case the operator program enters the override mode and poses the additional questions.

6. EFFECTIVENESS ANALYSIS

6.1 Man Overboard Model

The Man Overboard Computer Simulation Model (MOBCSM) provides the capability to study the effects of fourteen characteristics on the performance of rescue boats on eight ship types in man overboard situations. The MOBCSM was exercised to evaluate the effect of variations in ten of the most significant rescue boat characteristics on a single ship type and the effect of variation in one of these (the mean time to perform the standard maneuver) for each of the eight ship types. This exercise shows the relative importance of the various rescue boat characteristics to the performance of the rescue system: the relative importance of the rescue boat on various ship types, the relative effect of a single rescue boat characteristic on alternative ship types, and it also demonstrates the ability of the simulation model to perform effective analyses of these various parameters. The model is rich in its capability to study the effect of combinations of fourteen rescue boat characteristics, eight ships types, and three specific ship characteristics. The cases studies to date are just a small fraction of the cases that can and should be studied to gain a complete understanding of the effect of rescue boat characteristics on the rescue rate in man overboard situations on various ship types.

The study of the effect of rescue boat characteristics was performed by varying each rescue boat characteristic, one at a time, about a common "baseline" case. The baseline case is that of a conventional U.S.C.G. approved ship's motor lifeboat as it would currently be used in a man overboard situation on a typical large, modern containership. The studies thus indicate how the rescue rate of man overboards would be changed if rescue boats were used which had characteristics differing from conventional lifeboats in the indicated ways.

The baseline case ship is 710 feet long, underway at 23 knots, and has a mean course-keeping error of one degree. Five percent of the time the ship is unable to turn to the man in the water because of being in restricted waters, or for other reasons. The other characteristics of the ship and the environmental conditions are as listed in Table VI.

Characteristics of the rescue boat (or lifeboat) studied are:

1) a smooth water speed of 6 knots,
2) a speed of 3 knots in seas of eight feet significant wave height,
3) an open boat with two feet of freeboard,
4) the height of the lookout's eye at eight feet above the waterline,
5) 2 minutes to prepare for launch from conventional davits,
6) falls at the bow and stern with a rated descent speed of 100 feet per minute,
7) a sea state capability such that a prudent ship's captain would not attempt a launch in seas over 20 feet,
8) a maximum launch speed of 2 knots,
9) a rated time to perform the "standard maneuver" of 1.25 minutes, and
10) a 24 hour fuel endurance at rated power.

The boat is used for rescue in the conventional manner, that is, when a man falls overboard the boat is made ready for launch and held aboard the ship until the ship has returned close to the man and slowed (or stopped) to a speed at which the boat can be safely launched.

Figure 6-1 shows the results of 1000 man overboard simulations of the baseline case. A total of 284 persons were rescued by the rescue boat; this rescue rate of 0.284 is highlighted in

TABLE VI

SHIP CHARACTERISTICS: Baseline Case

Element Number	Variable	Description	
1	L_S	Ship Length	710 Ft
2	V_S	Ship speed	23 Knots
3	T_{SL_0}	Time to stop	2.6 Min.
4		Height of lookout's eye	60 Ft.
5	P_5	Probability ship is restricted from turning	0.5
6		Mode of sign. wave heights in mid-summer	3.0 Ft.
7		Mode of sign. wave heights in mid-winter	5.0 Ft.
8		Freeboard of ship	24.0 Ft.
9		Mean water temperature in mid-summer	70^oF
10		Mean water temperature in mid-winter	38^oF
11	P_{10}	Probability MOB will be recovered by ship rather than rescue boat	0.05
12		Mean heading error	1^o

FIGURE 6-1

MAN OVERBOARD SIMULATION

SIMULATION SERIAL NO. MOB 34

CONTAINER

LENGTH = 710 FEET SPEED = 23 KNOTS
NAVIGATIONAL HEADING ERROR = 1 DEGREE(S)
PROBABILITY SHIP WILL BE RESTRICTED FROM TURNING = 0.05
PROBABILITY SHIP WILL RECOVER MOB DIRECTLY = 0.05

RESCUE BOAT
SPEED: 6 KNOTS IN CALM WATER
3 KNOTS IN 8' SIGNIFICANT WAVE HEIGHT SEA
FREEBOARD = 2 FEET WITH 100 % OF GUNWALE OPEN
HEIGHT OF LOOKOUT'S EYE = 8 FEET
MEAN TIME TO PREPARE RESCUE BOAT FOR LAUNCH = 2 MINUTES
2 FALL(S) HAVING 100 FT./MIN. DESCENT SPEED
MAXIMUM SHIP SPEED FOR SAFE RESCUE BOAT LAUNCH = 2 KNOTS
RATED SEA STATE CAPABILITY = 20 FOOT SIGNIFICANT WAVE HEIGHT
MEAN TIME TO PERFORM STANDARD MANEUVER = 1.25 MINUTE(S)
PROBABILITY RESCUE BOAT WILL BE DEPLOYED TO SEARCH WITH SHIP = 0

RESULTS OF 1000 SIMULATIONS:

OVERALL FRACTION OF ********
MOB'S RESCUED * 0.284*
BY RESCUE BOAT ********

RESCUE BOAT DEPLOYED 556 TIMES
RESCUE BOAT LAUNCH FAILED 0 TIMES DUE TO SEA STATE

	MOB SEEN 639 TIMES				MOB NOT SEEN 361 TIMES			
	NO. TIMES	MEAN	MIN.	MAX.	NO. TIMES	MEAN	MIN.	MAX.
MOB ALIVE WHEN:								
BRIDGE NOTIFIED	636	1.00	0.00	2.00	106	9.04	0.48	32.99
MOB'S POS. REACHED	537	5.70	0.30	16.09	37	17.03	5.21	70.22
MOB FOUND	528	5.83	3.74	16.09	37	17.03	5.21	70.22
ABOARD RESCUE BOAT	438	8.38	5.49	16.87	18	21.90	10.02	73.85
MOB SAVED	270	8.28	5.49	16.87	14	20.80	10.02	73.85

Figure 6-1 by the boxed asterisks. Note that the total number of persons rescued was 303; the additional 19 were rescued directly by the ship. Four hundred fifty six (456) people were actually recovered from the water by the rescue boat. The difference between the number of people recovered by the rescue boat (456) and the number actually saved (284) is the number of people lost during transfer (172) from the boat to the ship reflecting the hazardous aspect of this phase of the rescue operation.

The performance of the rescue boat in recovering the MOB (exclusive of searching for him in those 5 percent of the simulated incidents) is more directly measured by the ratio of the number recovered to the number of MOBs found. This ratio can be considered the rescue boat's "effectiveness". In the baseline case this ratio is 456 to 565 for an effectiveness of 0.807.

Note that the statistics of the simulation indicate that 435 MOBs perish before they are found (1000-565). Since the specification of the baseline case calls for the ship to conduct the search in 95 percent of the simulated incidents, these 43.5% of the MOBs were lost largely without regard to the rescue boat's characteristics. The ship (or boat) managed to reach the MOBs position in 574 of the incidents, therefore only 9 were lost because they could not be seen when the ship or boat reached their position (i.e. when the navigational error exceeded the distance of visibility).

The results of the simulation show that a MOBs chance of being saved is strongly dependent upon whether he was seen entering the water or not. Consistent with the statistical inputs to the MOBCSM, 63.9% of the MOBs in the baseline case were seen entering the water. Figure 6-1 shows the separate outcomes of these and those of the 36.1% who were not seen falling overboard. The breakdown of the disposition of the MOBs in each category

can be visualized in the chart shown in Figure 6-2. The most striking feature of Figure 6-2 is the wide disparity in the numbers of people still alive when the bridge is notified that a man has fallen overboard. There are two reasons for this; first, when the man is seen falling overboard it is never more than four minutes until the bridge is notified, and usually much sooner. When the man is not seen falling overboard, however, the bridge is never notified sooner than 15 minutes later; the mean time for this notification is more like 56 minutes. Thus, the survival time for a man who is not seen falling overboard is far more likely to be exceeded before the bridge is notified that he is missing than is the case when he is seen falling overboard. The second reason is that a man who is not seen falling overboard is only one-fourth as likely to be wearing a personal floatation device than a man who is seen falling overboard. Consequently, these people who are not seen falling overboard must not only wait a longer time for rescue action but they must do so, for the most part, without the assistance of personal floatation devices. This all leads to far fewer of the people who are not seen entering the water being alive when the bridge is notified than otherwise.

The chart shows that more people in the "seen" than the "not seen" category are lost while the ship is returning to their position (98 versus 69) but this, of course, is due to more lives being at risk. Only 35 percent of the "not seen" MOBs, versus 84 percent of the "seen" MOBs, are still alive when the ship returns to their position.

As modelled, the ability of the ship (or boat) to return to the MOBs true position is shown to be an insignificant factor in the rescue effort. All of the "not seen" MOBs and all but 9 of the "seen" MOBs who were still alive were found when the ship returned to a position abeam of where the man fell overboard.

MAN OVERBOARD SIMULATION (SERIAL NO. 34)

CONTAINERSHIP

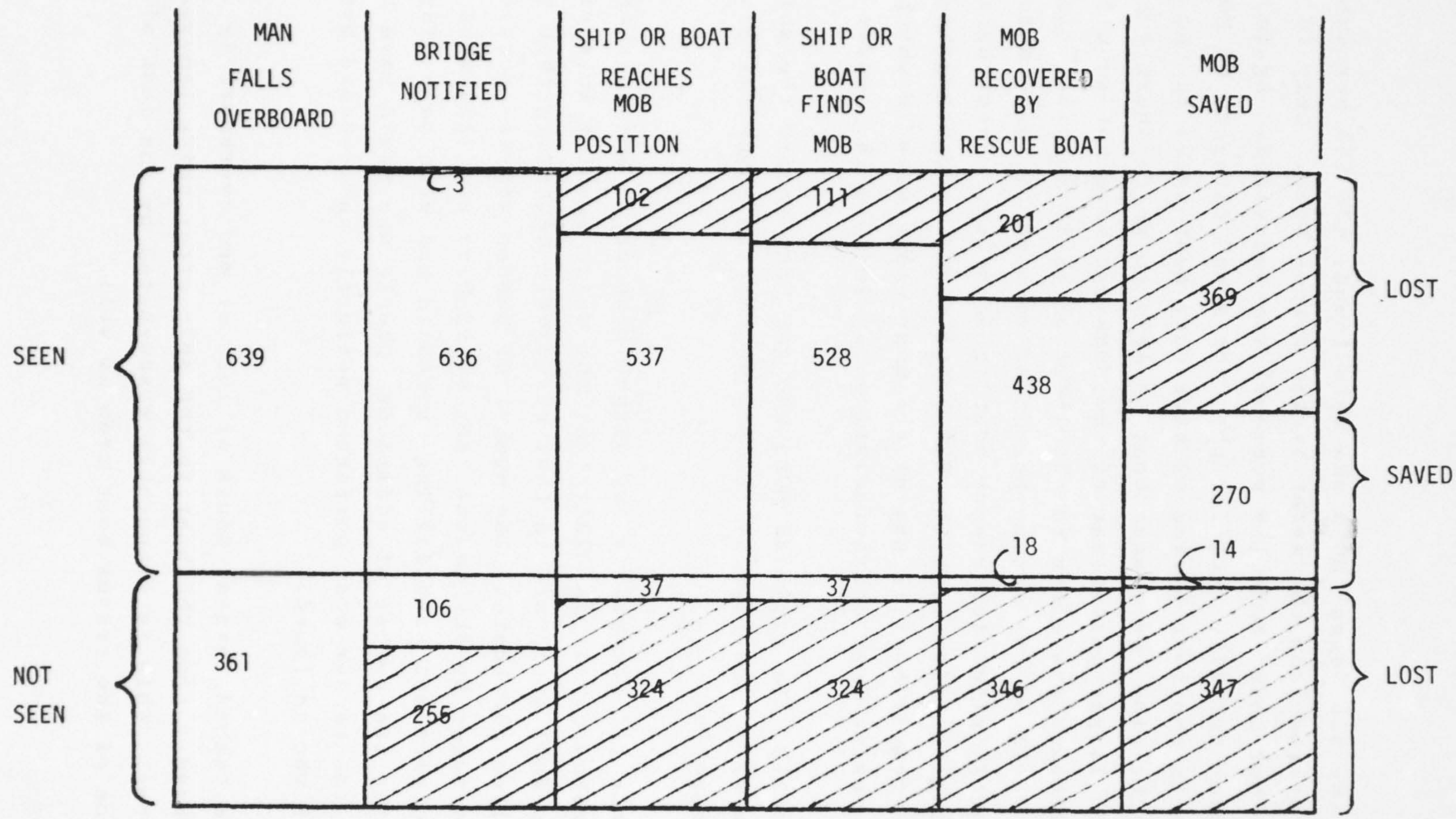


FIGURE 6-2. CHART OF NUMBER OF PEOPLE ALIVE OR DEAD AT COMPLETION OF SELECTED EVENTS

Of the 528 "seen" MOBs who were found, 438 (83 percent) are recovered from the water by the rescue boat. Only 18 of the 37 "not seen" MOBs (49 percent) are recovered. Again, the higher fatality rate for the "not seen" category of MOBs is due to the long period of time they must spend in the water. By the time the rescue boat is able to go to their rescue, a much larger percentage of the MOBs who were not seen falling overboard are close to the limit of their survival time. It is no fault of the rescue boat that so many of these MOBs are lost shortly after the rescue boat is launched. Nevertheless, shortening the time from the MOB being found to getting him on board the rescue boat is one of the most basic ways in which changes in rescue boat characteristics can improve the rescue rate.

Finally, the ratio of MOBs who get back aboard the ship to those who were recovered by the rescue boat is about the same for both categories.

Table VII summarizes the disposition of individuals who fall overboard. It is clear that the major problem in saving people who fall overboard is that of quickly detecting that they have fallen overboard. The number of people who are recovered from the water by the rescue boat would have been 229 more if those who were not seen falling overboard had been seen. This is more than twice the number of additional people who would have been saved if the rescue boat performed perfectly and rescued every single MOB who is found.

The second largest cause of loss of men overboard is in their recovery from the boat to the ship after being removed from the water. This is frequently exacerbated by the loss of all or some of the rescue boat crew as well.

TABLE VII

PRINCIPAL CAUSES OF LOSSES OF MEN OVERBOARD

	Percent
Lost before bridge knows man is overboard	25.8
Lost due to failure of boat recovery after rescue	17.2
Lost during rescue boat operations	10.9
Lost while ship (or boat) returns to man who was seen falling overboard	9.9
Lost while ship (orboat) returns to man who was not seen falling overboard	6.9
Lost because ship (or boat) can not find man who was seen falling overboard	0.9
Saved	28.4
TOTAL	100.0%

One of the most obvious areas for improvement in the rescue rate of man overboards (at least as far as the performance of the rescue boat can affect it) is the quickness of the boat in getting from the side of the ship to the man in the water. As discussed earlier (in Section 4.1.5), this quickness is a function of a number of the rescue boat's attributes including its speed, maneuverability, and seaworthiness; all of which have been aggregated in a single performance characteristic called the "rated time to perform the standard maneuver", T_{SM}. The effect of this characteristic on the rescue rate was examined with the MOBCSM by varying the value assumed for the baseline case while holding the values of all other variables constant. The results are shown in Figure 6-3. They confirm the expectation that the rescue rate can be improved by increasing the rescue boat speed in performing the standard maneuver. The sensitivity, however, is somewhat low. If sensitivity is defined as the percentage change in the rescue rate due to the change in T_{SM} divided by the percentage change in T_{SM}, then the sensitivity turns out to be 10%. The effect of the time to perform the standard maneuver on the rescue boat's "effectiveness" in rescuing men overboard who have been found is shown in Figure 6-4. The rescue boat "effectiveness" is defined as the ratio of the number of people saved to those still alive when the rescue boat begins its rescue effort. These are the only people whose destiny can be influenced by a change in rescue boat characteristics and so the "effectiveness" is a more direct measure of rescue boat performance than the rescue rate. The rescue rate does, however, put the issue of rescue boat performance in its proper context and identifies the limitations on boat improvements in reducing loss of life. Figure 6-4 shows that rescue boat effectiveness is improved 2.4 percent (from 0.807 to 0.831) when the time to perform the standard maneuver is reduced by a factor of two from 1.25 to 0.65 minutes and reduced 6.7 percent (from 0.807 to 0.740) when the time is doubled from 1.25 to 2.5 minutes.

MAN OVERBOARD

CONTAINERSHIP

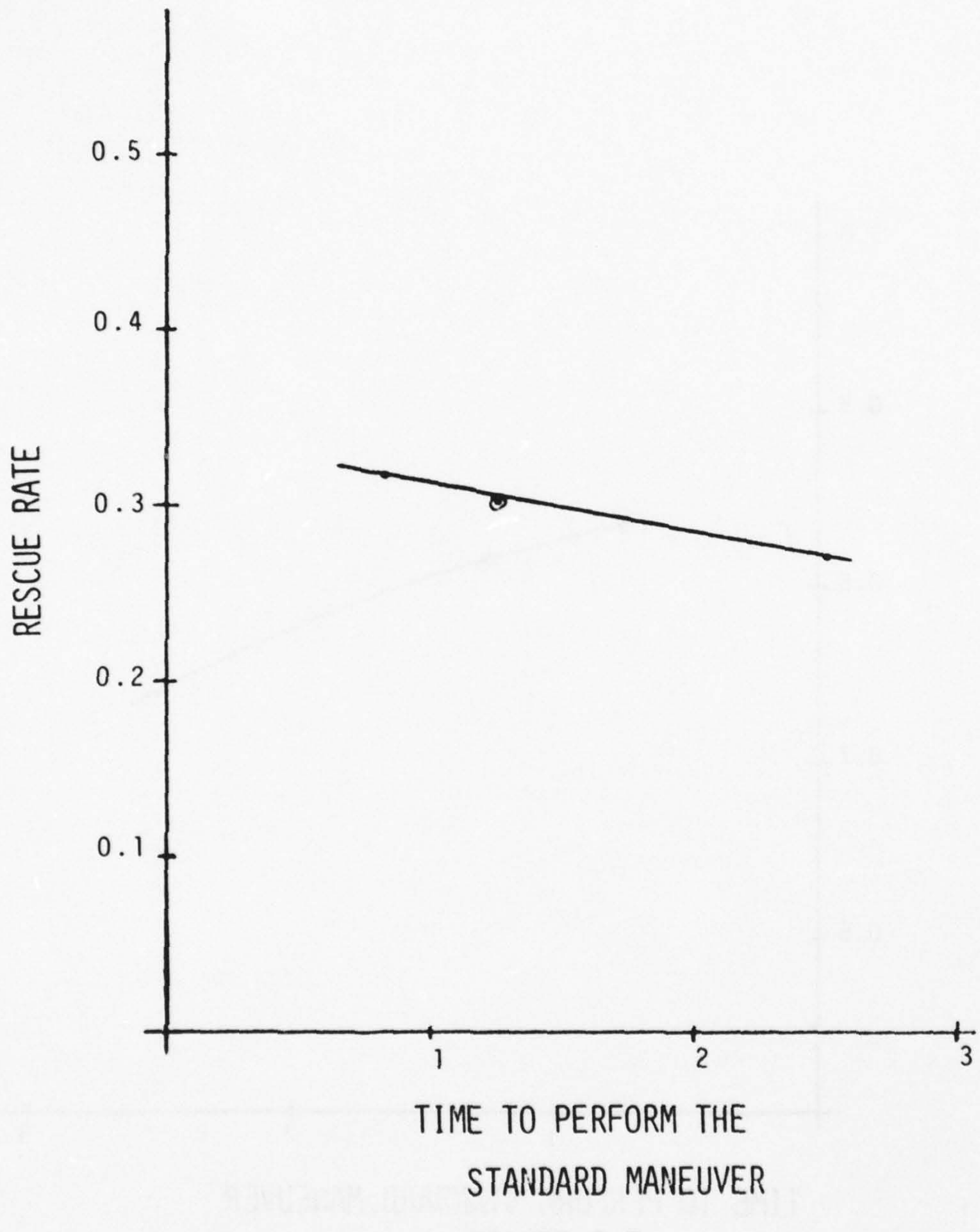


FIGURE 6-3

MAN OVERBOARD

CONTAINERSHIPS

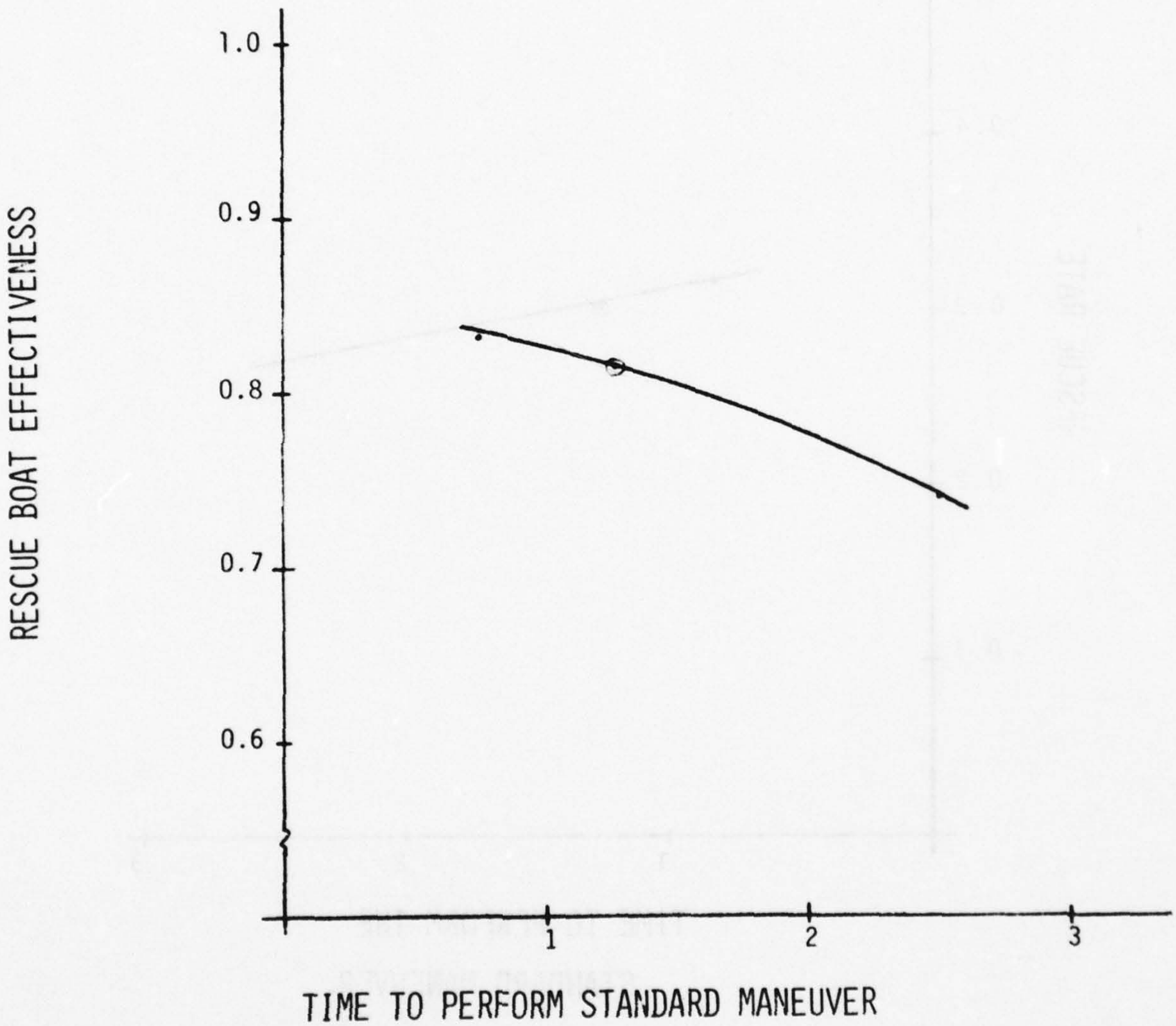


FIGURE 6-4

In a separate analysis, histograms of the times in which each MOB in the simulation was saved by the rescue boat were generated. These help to develope an understanding of the mechanism by which the rescue boat's speed in performing the standard maneuver impacts the rescue rate. In Figure 6-5 the histogram for the time to be saved is superimposed on the survival time of all 1000 people who fell overboard for the baseline case where the standard maneuver time is 1.25 minutes. It can be seen that the boat is almost totally effective in rescuing those few people who have a relatively long survival time, say greater than 30 minutes. The rescue rate decreases sharply as the survival time falls below 30 minutes. Only 6.6 percent of the people with a survival time less than 10 minutes (the modal time for the 77 percent who do not have floatation) are rescued. A similar comparison of the rescue time and survival time histograms for the case where the time to perform the standard maneuver is reduced to 0.65 minutes is shown in Figure 6-6. While there is little change in the overall rescue rate, there is a significant increase in the rescue rate of people with short survival times. For example, the rescue rate for people with survival times less than 10 minutes nearly doubles to 12.4 percent. A histogram of the additional people saved due to cutting the standard maneuver time in half is shown in Figure 6-7 (corrected for statistical variations) and reveals that the impact on the rescue rate is greatest for the shortest survival time category, as expected.

The effect of variations in the time to perform the standard maneuver was examined for each of the eight standard ship types. The results are shown in a composite graph in Figure 6-8. The lower rescue boat effectiveness for fishboats, tugs, and ferries when compared to the other five ship types reflects the greater likelihood that the MOB will be recovered directly by the vessel itself. The slope of the tugboat curve is more pronounced than that of the fishboat and ferry curves; this reflect a greater

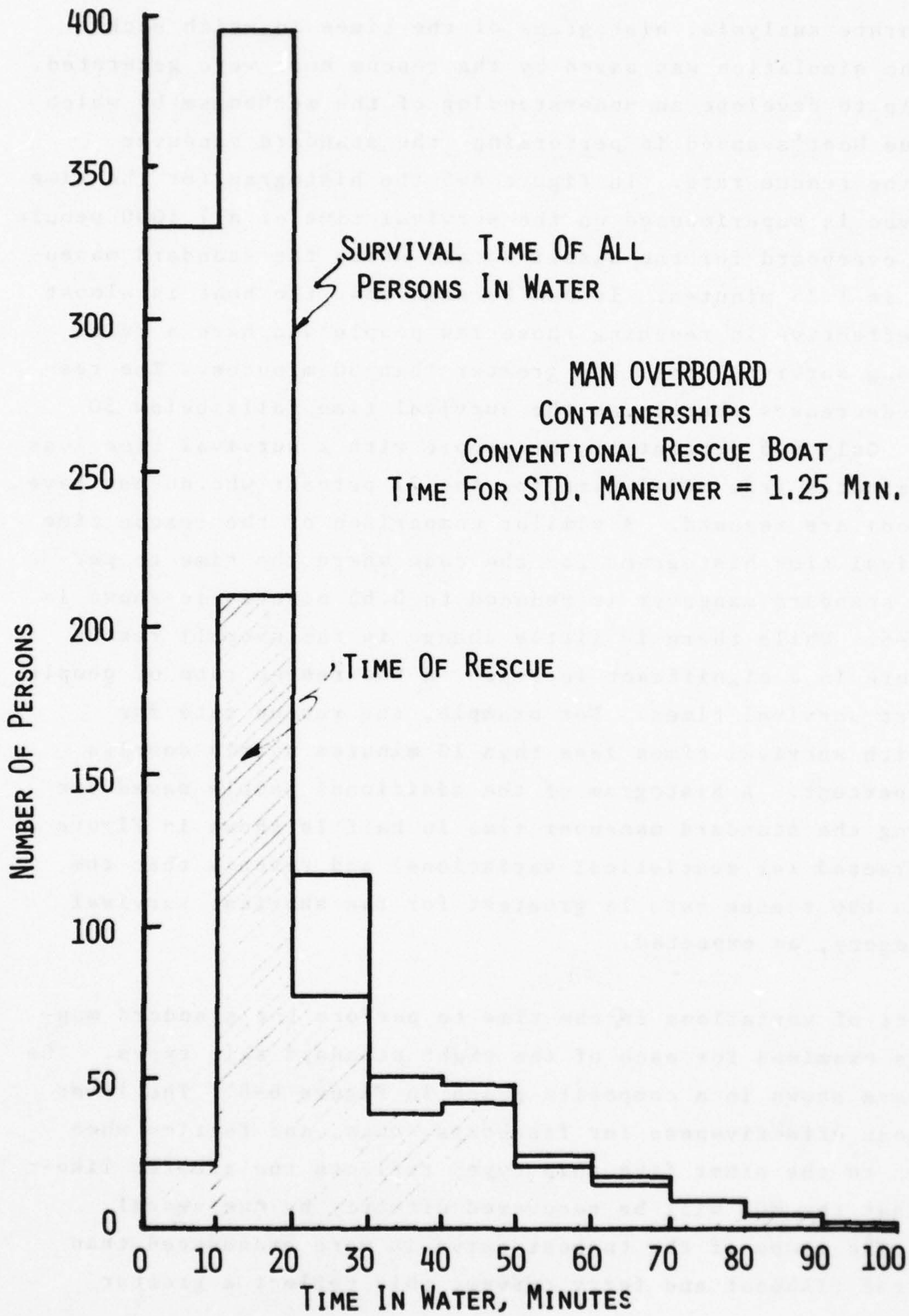
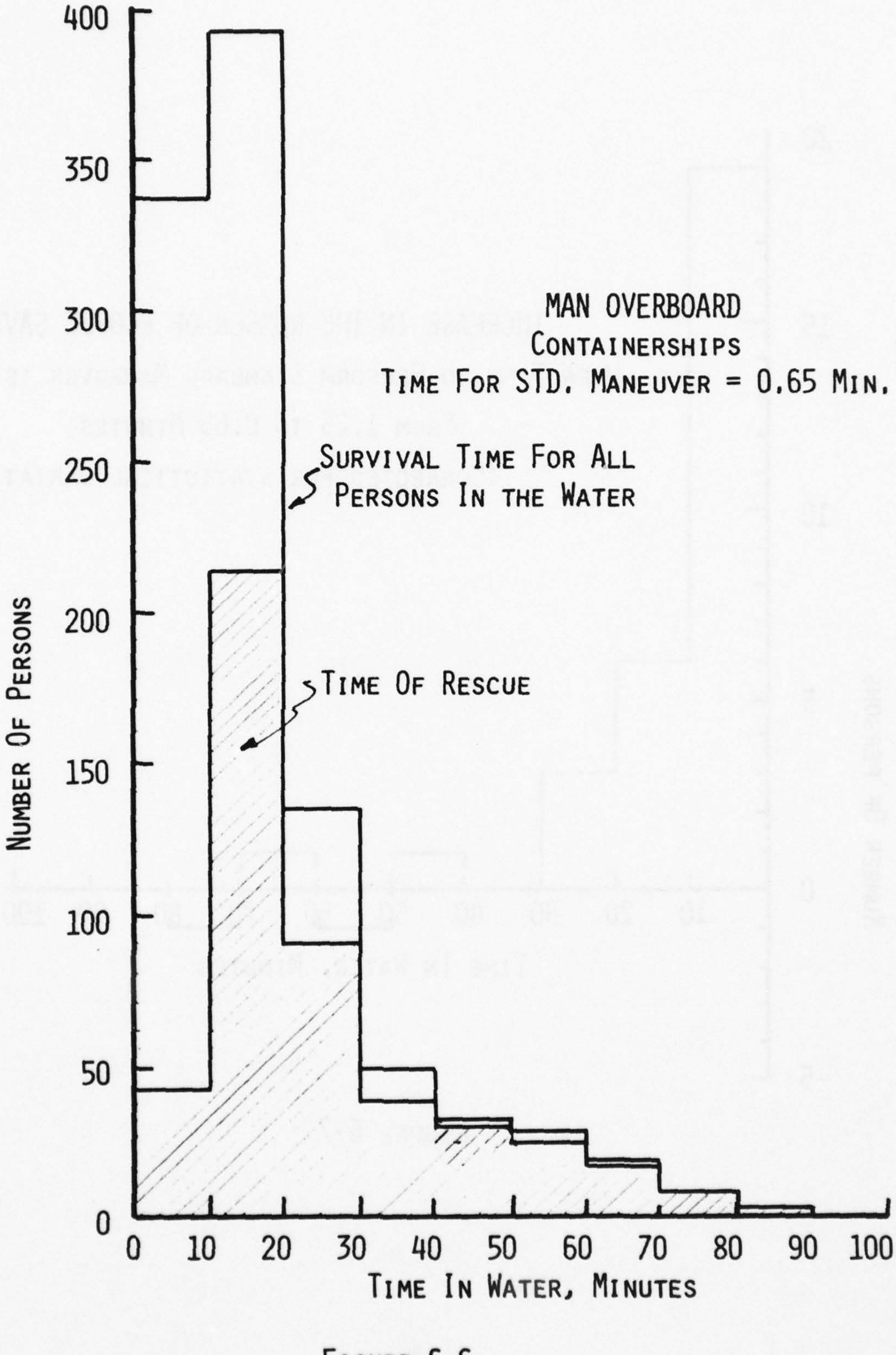

400
350
300
250
200
150
100
50
0
Number Of Persons
Survival Time Of All Persons In Water
Man Overboard
Containerships
Conventional Rescue Boat
Time For STD. Maneuver = 1.25 Min.
Time Of Rescue
0
10
20
30
40
50
60
70
80
90
100
Time In Water, Minutes

Figure 6-5



MAN OVERBOARD
CONTAINERSHIPS
TIME FOR STD. MANEUVER = 0.65 MIN.
SURVIVAL TIME FOR ALL PERSONS IN THE WATER
TIME OF RESCUE
NUMBER OF PERSONS
400
350
300
250
200
150
100
50
0
0 10 20 30 40 50 60 70 80 90 100
TIME IN WATER, MINUTES

FIGURE 6-6

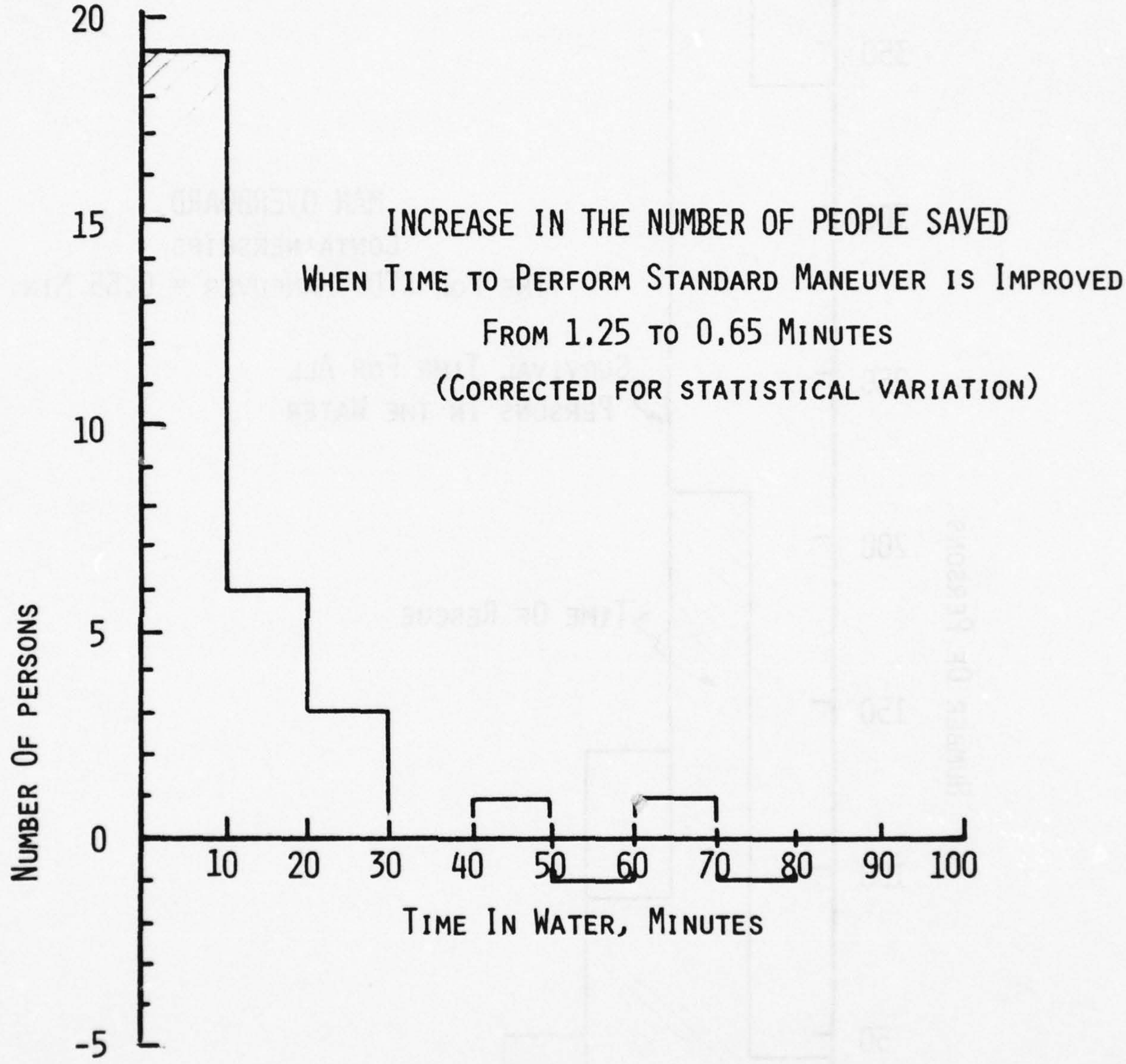

INCREASE IN THE NUMBER OF PEOPLE SAVED
WHEN TIME TO PERFORM STANDARD MANEUVER IS IMPROVED
FROM 1.25 TO 0.65 MINUTES
(CORRECTED FOR STATISTICAL VARIATION)
NUMBER OF PERSONS
20
15
10
5
0
-5
10
20
30
40
50
60
70
80
90
100
TIME IN WATER, MINUTES

FIGURE 6-7

MAN OVERBOARD

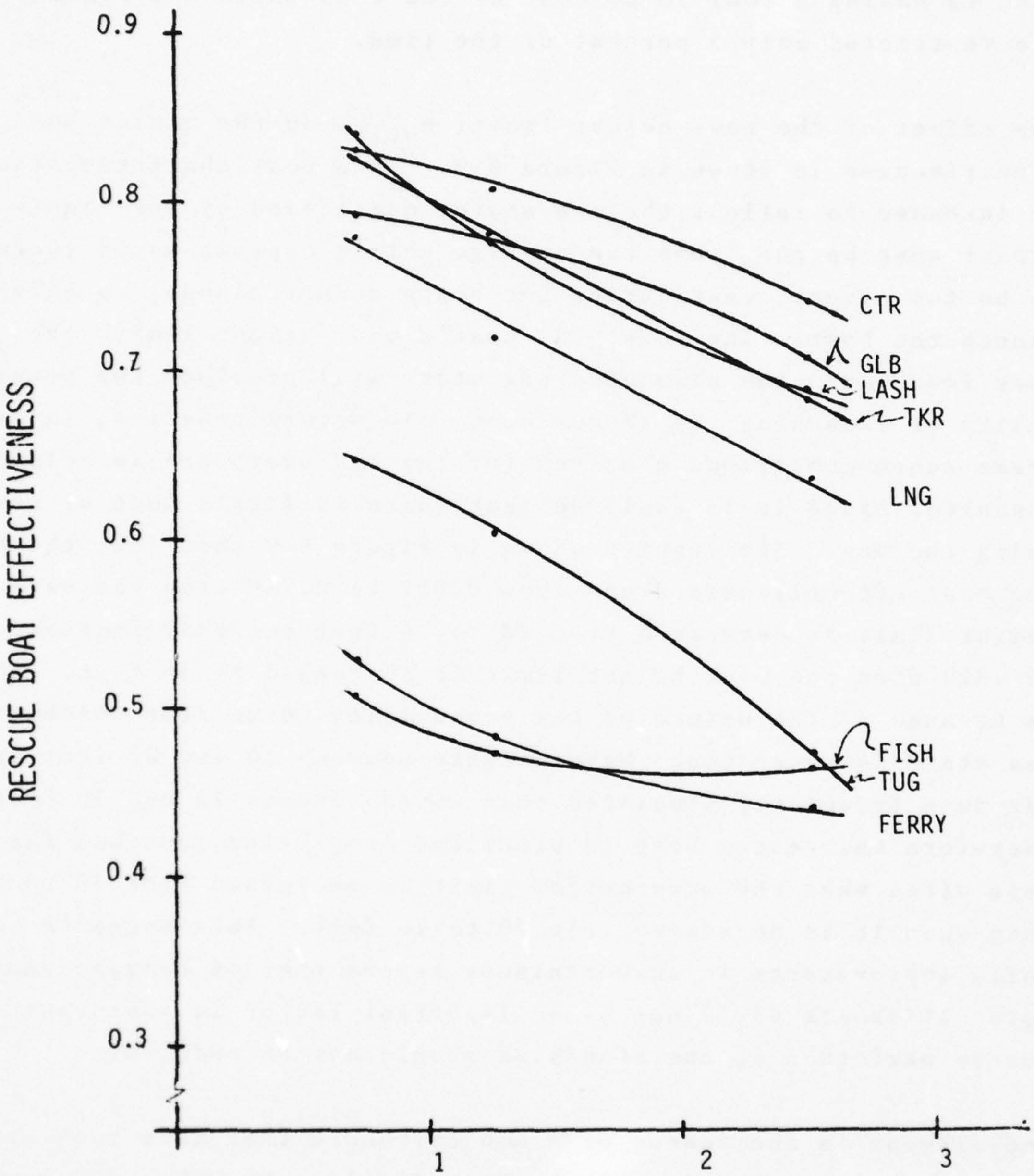


FIGURE 6-8

sensitivity to the time to perform the standard maneuver, because the tugboat is specified to be restricted from turning (due to having a tow) 50 percent of the time while the others are restricted only 5 percent of the time.

The effect of the wave height limit, h_{wLIM}, on the rescue boat effectiveness is shown in Figure 6-9. This boat characteristic is intended to reflect the sea state, quantified by the significant wave height, that the average ship's captain would judge to be too severe, considering the boats seaworthiness, to safely launch the boat. The lower the boat's wave height limit, the more frequently the simulated sea state will preclude the possibility of launching the rescue boat. In actual practice, in extreme storm conditions a search for the man overboard is seldom conducted since it is realized that there is little hope of rescuing the man. The results shown in Figure 6-9 show that the rescue boat effectiveness drops from 0.807 to 0.738 when the wave height limit is decreased from 20 to 10 feet but only increases to .819 when the wave height limit is increased to 30 feet. This is because of the nature of the probability curve from which the sea state is generated. Wave heights between 10 and 20 feet are far more frequently simulated than waves between 20 and 30 feet, therefore the rescue boat is precluded from being launched far less often when the wave height limit is decreased from 30 to 20 feet than when it is decreased from 20 to 10 feet. This suggests that while improvements in seaworthiness beyond that of conventional motor lifeboats would not be an important factor in improving rescue performance, the standards should not be reduced.

One element in the rescue of a man overboard that gets much attention is the time to prepare the boat for launch. When man overboard drills are conducted, the measure of success of the drill is usually the time interval from the sounding of the alarm to the boat being reported ready for launch. Although the time to

MAN OVERBOARD

CONTAINERSHIPS

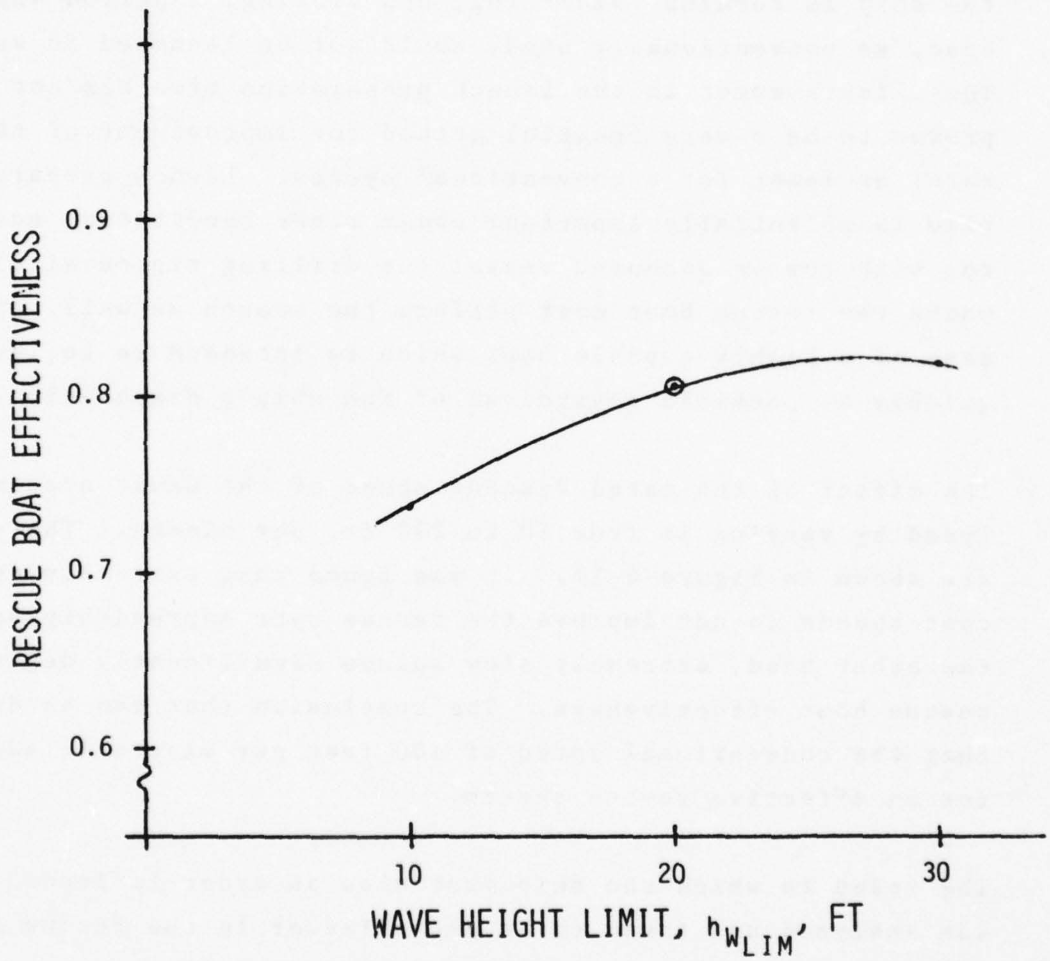


FIGURE 6-9

prepare the boat for launch is primarily a characteristic of the crew, it is to some extent a characteristic of the boat and its launching system. Design features can enable the boat to be prepared more quickly. The results of varying the time to prepare the boat for launch are shown in Figure 6-10. There is little discernable effect in the rescue boat effectiveness due to variations in the time to prepare the boat for launch. This is explained by noting that the boat is prepared for launch while the ship is turning, searching, and slowing; a period when the boat, as conventionally used, would not be launched in any case. Thus, improvement in the launch preparation time has not been proven to be a very fruitful method for improvement of the rescue rate, at least for a conventional system. Launch preparation time is potentially important under other conditions, such as a tug with tow or anchored vessel (or drilling rig on site), where the rescue boat must perform the search as well, or in the case of a highly capable boat which is intended to be launched as quickly as possible regardless of the ship's disposition.

The effect of the rated descent speed of the davit system was analysed by varying it from 50 to 200 ft. per minute. The results are shown in Figure 6-11. It was found that extremely fast descent speeds do not improve the rescue rate appreciably but on the other hand, extremely slow speeds significantly degrade the rescue boat effectiveness. The conclusion that can be drawn is that the conventional speed of 100 feet per minute is adequate for an effective rescue system.

The speed to which the ship must slow in order to launch the boat was analyzed and found to be not a factor in the rescue boat effectiveness. The results are shown in Figure 6-12.

The effect of freeboard between one and four feet is shown in Figure 6-13. It was found that moderate changes in the freeboard have little effect on the rescue boat effectiveness al-

MAN OVERBOARD

CONTAINERSHIPS

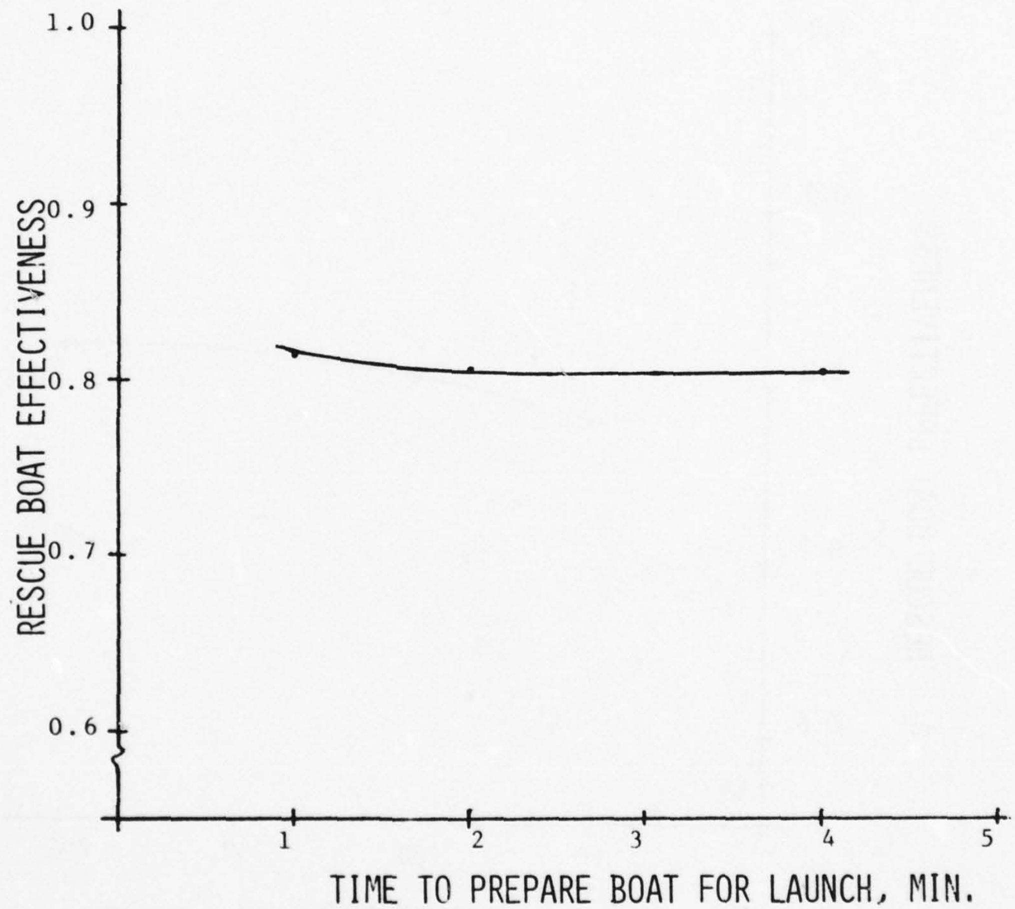
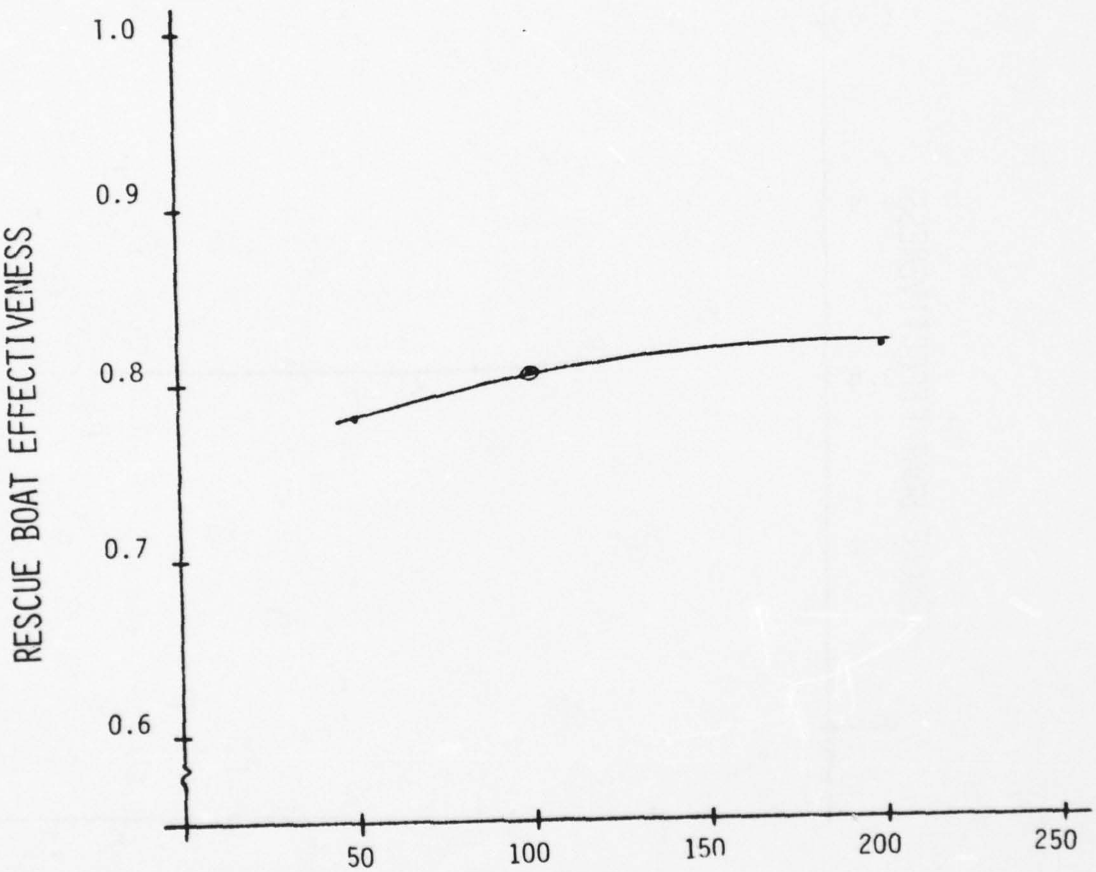


FIGURE 6-10

MAN OVERBOARD

CONTAINERSHIPS



DESCENT SPEED, V_D, FT/MIN

FIGURE 6-11

MAN OVERBOARD

CONTAINERSHIPS

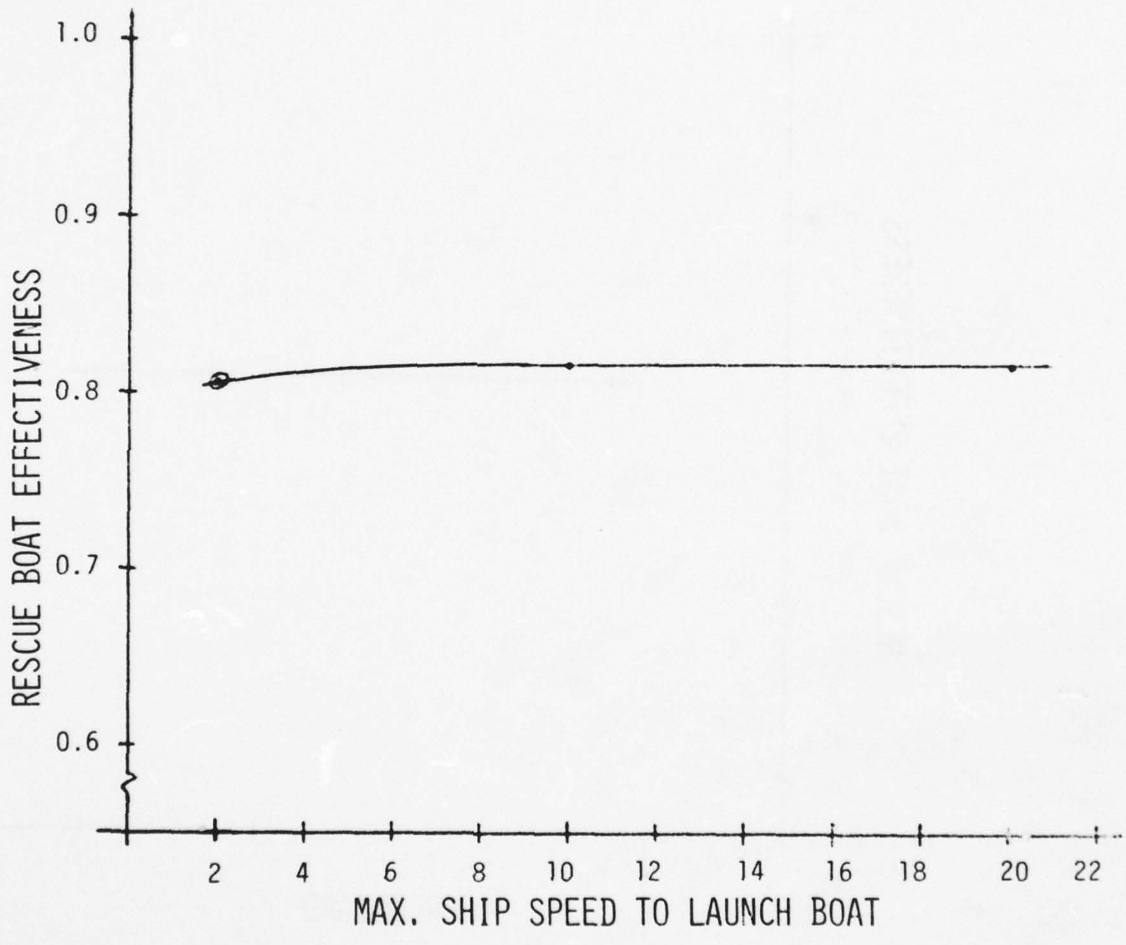


FIGURE 6-12

MAN OVERBOARD

CONTAINERSHIPS

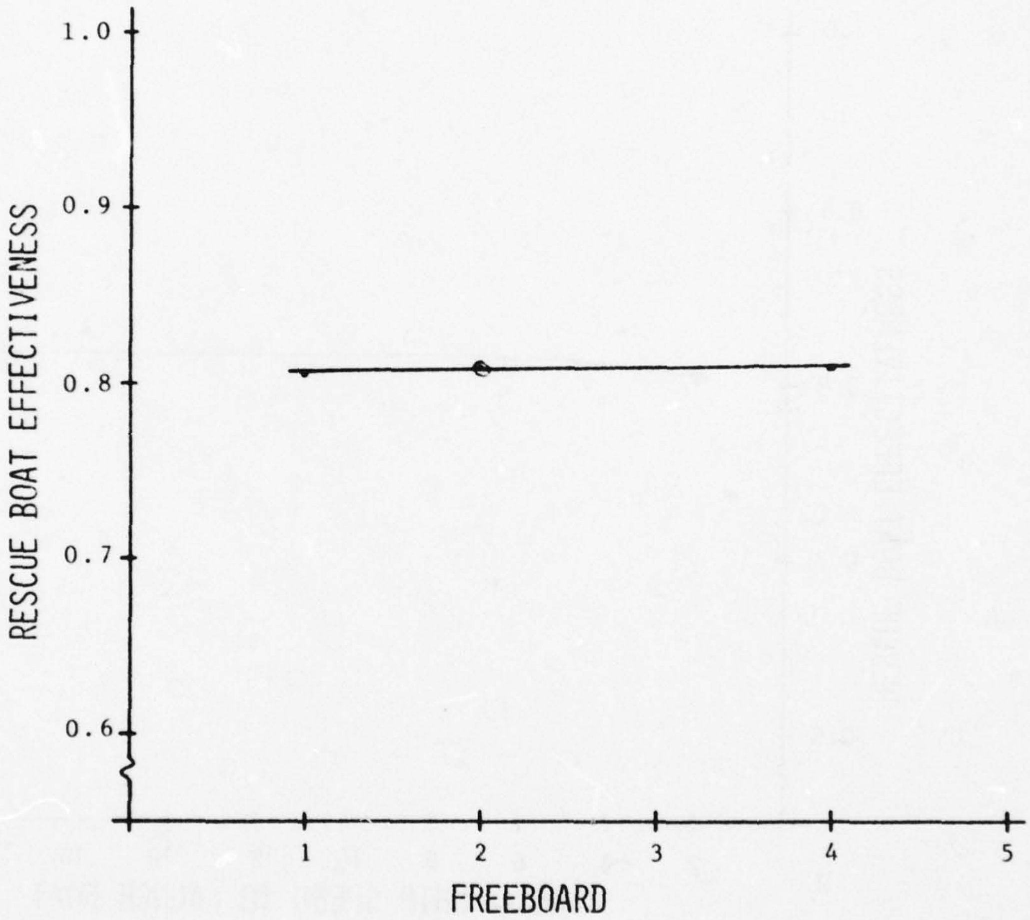


FIGURE 6-13

though it is expected that very high freeboards would degrade rescue performance if some auxiliary means were not provided to remove a helpless survivor from the water. The reason for the low sensitivity of the rescue rate to moderate changes in the freeboard is that removing the man from the water takes a relatively small portion of the total rescue time.

To determine the extent to which enclosures impede the rescue performance, the percent of length of the rescue boat that is open was varied from 10 to 100 percent. The results are shown in Figure 6-14. There is no significant difference in the rescue boat effectiveness between 50 percent and 100 percent open boats. With only 10 percent of the gunwale length open, however, the rescue boat effectiveness falls to 0.35. The exact shape of the curve is yet to be determined but the general conclusion can be drawn that while some amount of open rail space is required to facilitate a speedy rescue, a completely open boat is not essential for good performance.

In general, a change in the time to perform the standard maneuver, i.e. the boat's agility, will be associated with a corresponding change in the rescue boat speed. In these analyses, the effect of boat characteristics are evaluated one at a time in order to better understand the mechanism by which each characteristic affects the rescue rate. In the analyses of the effect of the time to perform the standard maneuver, the boat speed in calm water was held constant at 6 knots. The results of an analysis of rescue boat speed with time to perform the standard maneuver held constant at the baseline value of 1.25 minutes are shown in Figure 6-15. Since the significance of rescue boat speed to the rescue rate is solely through the effect of the number of MOBs found alive, Figure 6-15 shows the fraction of MOBs found alive. When the ship cannot (or does not) participate in the search, the effect of boat speed is pronounced, as would be

MAN OVERBOARD

CONTAINERSHIPS

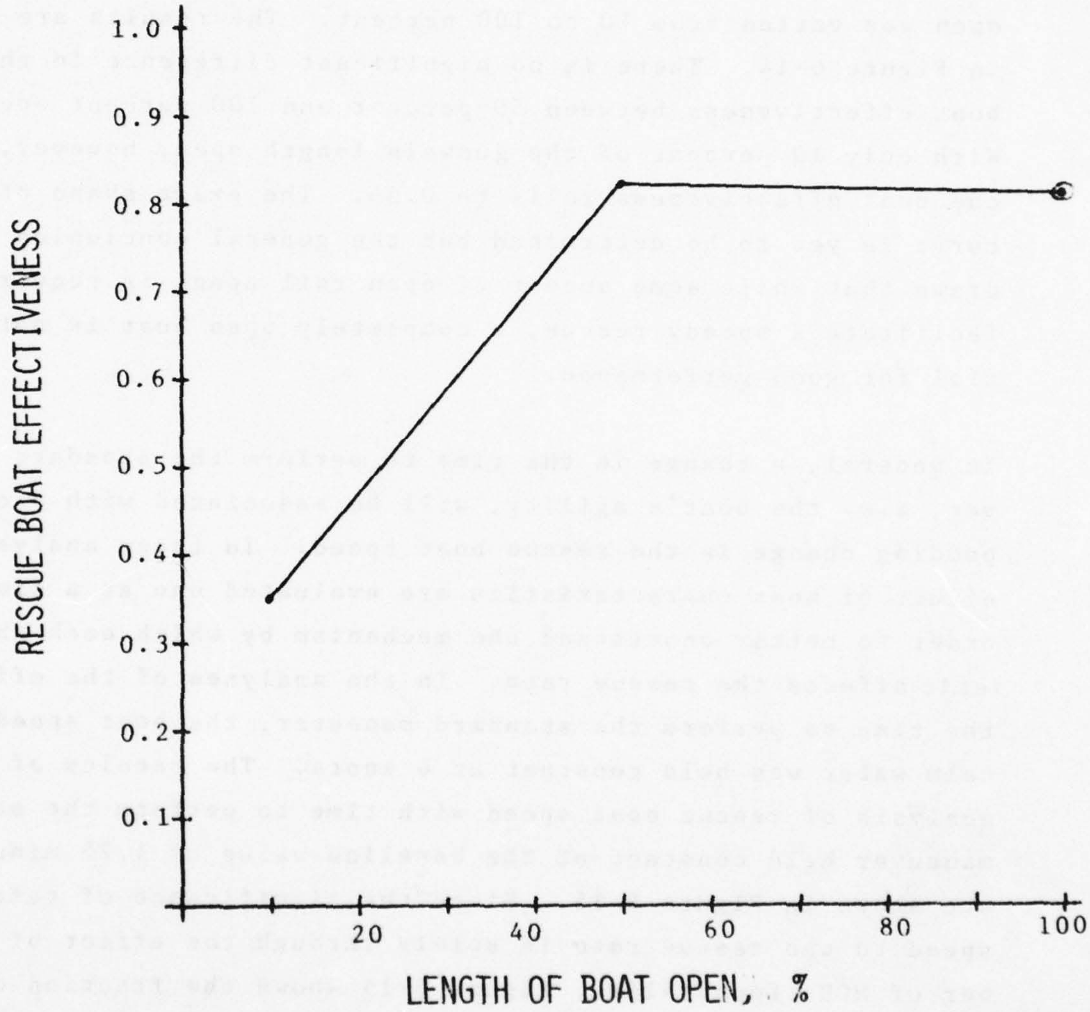


FIGURE 6-14

MAN OVERBOARD

CONTAINERSHIPS

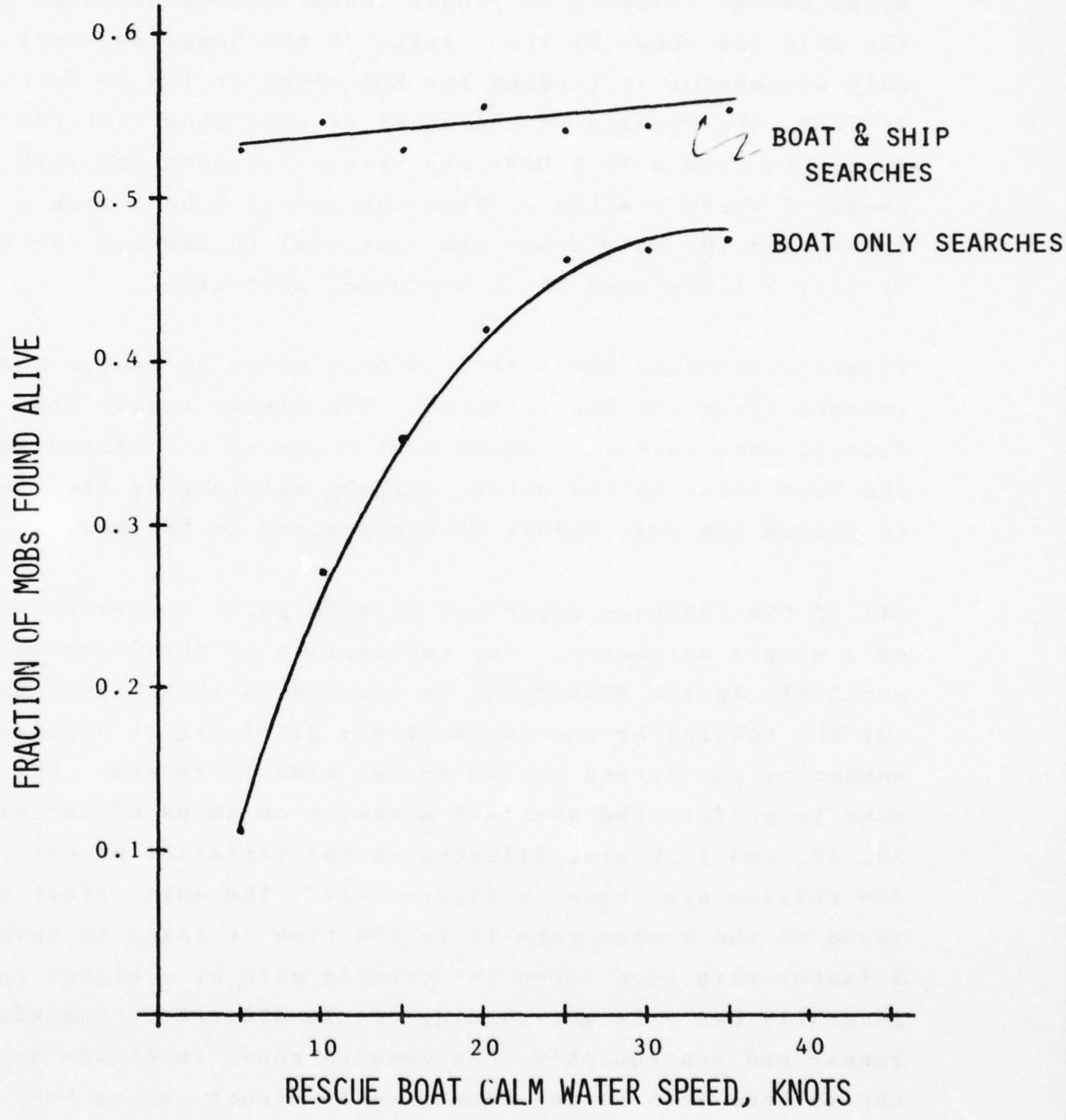


FIGURE 6-15

expected. Only 11 percent of all MOBs are found alive when the rescue boat speed is 5 knots. The rate increases rapidly as boat speed is increased but seems to peak at 30 knots. When the ship and boat both are used to conduct the search, the effect of boat speed on the fraction of people found is considerably less since the ship (as shown by the results of the baseline case) is reasonably successful at finding the MOB alive at its 23 knot speed. In fact, the results of the baseline case show that the ship failed to find only 9 MOBs who were alive when the ship returned abeam of their position. Thus the use of a boat with a slower speed then the ship's has the potential to improve the rescue rate by only 9 lives even if it performed perfectly.

Figure 6-16 shows the effect of boat speed on rescue boat effectiveness after the man is found. The higher rescue boat effectiveness when only the rescue boat conducts the search is due to the boat being in the water, thereby eliminating the time required to launch the boat before it can proceed to the man.

All of the analyses described to this point concerned variations of a single parameter. Any combination of the 25 variables available in the MOBCSM can be changed as the analyst desires but the results become increasingly difficult to explain as the number of parameters varied at one time increases. The effect of time to perform the standard maneuver on ships of various speeds: 23, 18, and 12 knots, illustrates the variation of two parameters. The results are shown in Figure 6-17. The main effect of ship's speed on the rescue rate is in the time it takes to turn. While a faster ship negotiates the turning path at a higher speed it generally has a larger turning circle diameter. The effect is nonlinear and consequently, the results shown in Figure 6-17 show the 18 knot ship having consistently higher rescue boat effectiveness because it negotiates the turn faster than the 12 or 23 knot ships.

MAN OVERBOARD

CONTAINERSHIPS

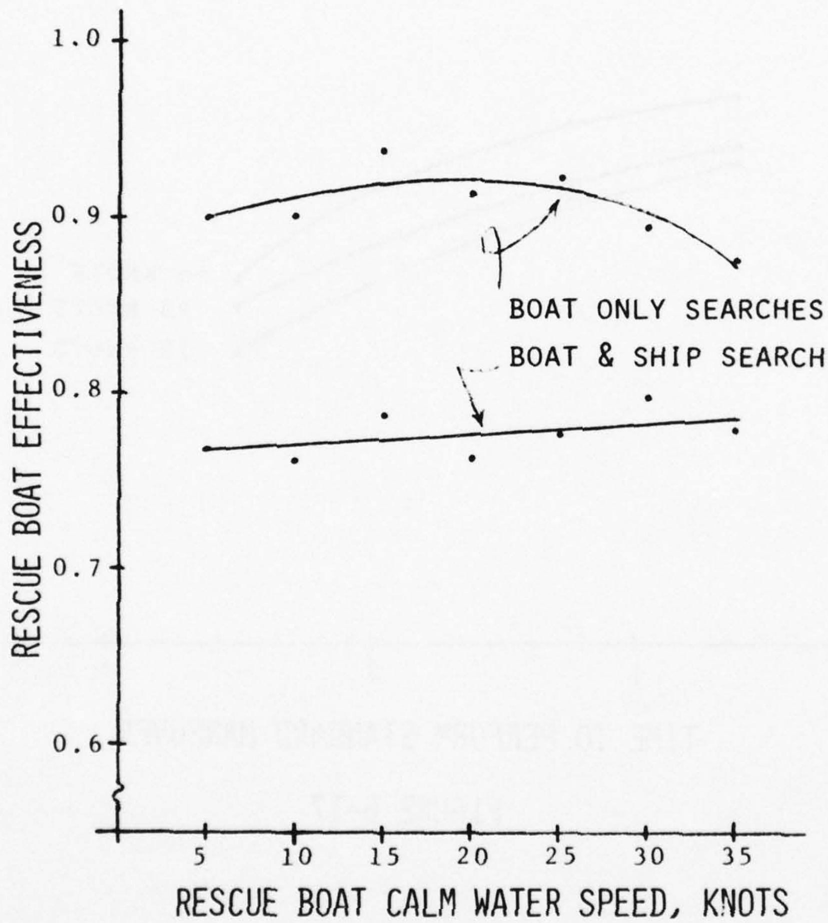


FIGURE 6-16

MAN OVERBOARD

CONTAINERSHIPS

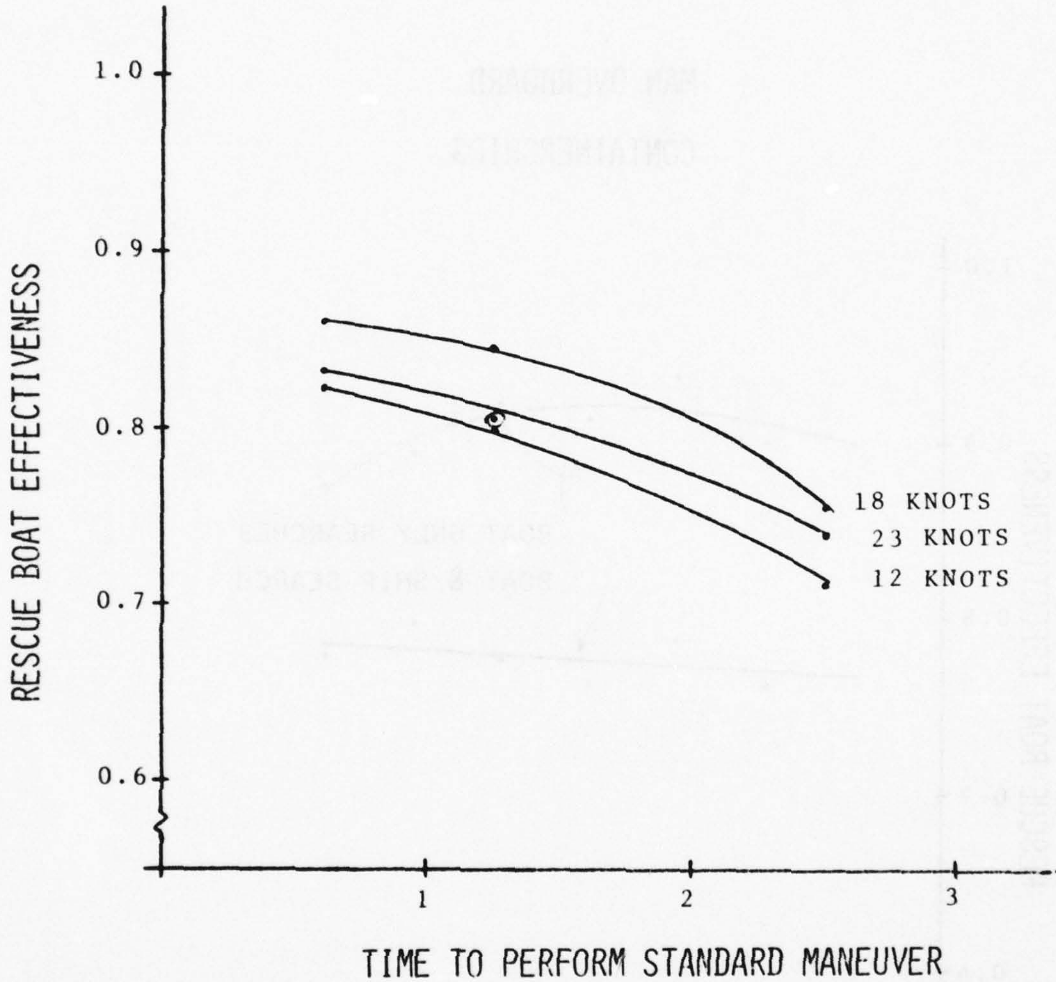


FIGURE 6-17

The baseline case incorporates a conventional double fall davit system. The effect of a single fall system on the rescue rate was also examined by changing this parameter only. The rescue rate increased from 0.303 to 0.321 primarily because the number lost during transfer from the rescue boat back aboard the ship decreased from 172 to 168.

6.2 Abandon Ship

The Abandon Ship Computer Simulation Model (ASCSM) provides the capability to study the effect of eight rescue boat characteristics on the performance of rescue boats on eight ship types involved in nine types of ship casualties leading to ship abandonment.

The effect of variation in the six most important rescue boat characteristics on the rescue rate was studied by varying each characteristic one by one while holding all of the other characteristics constant at the values corresponding to a "baseline" case. The baseline corresponds to a conventional ship's lifeboat used as the rescue boat in the abandonment of a containership involved in an explosion and sinking casualty. Figure 6-18 shows the results of the simulation of the baseline case (designated Serial No. AS 102) and is representative of the program output for the Abandon Ship Simulations. The single page output sheet for each simulation run, shown in Figure 6-18, also displays the values of the rescue boat, ship, and the primary casualty characteristics which constitute the input data for the particular case being analyzed.

Figure 6-18 shows that over the 300 simulated abandon ship incidents, the rescue rate was 0.308, that is, 30.8 percent of the people who entered the water due to the casualty and subsequent abandonment were rescued by the rescue boat. The rescue rate does not mean that these are the only people rescued and that the rest are lost because people not rescued by the rescue boat may be rescued by other means such as lifeboats or liferafts or boats from nearby vessels, etc. The rescue rate as used in the ASCSM is intended to provide a direct measure of the rescue boat's performance only; it is not intended to consider the total rescue performance.

Figure 6-18 also shows that over the 300 simulated abandon ship incidents there were an average of 3.01 people in the water each time, and in individual simulations, as few as none and as many

ABANDON SHIP SIMULATION

SIMULATION SERIAL NO. AS 102

CONTAINER
LBP = 710 FEET
POB = 40
2 - 40 MAN LIFEBOATS
1 - 25 MAN LIFERAFTS

NUMBER OF RESCUE BOATS = 1
RESCUE BOAT CAPACITY = 15 + 2 MAN CREW (EACH BOAT)
MEAN TIME TO LAUNCH RESCUE BOAT = 2 MINUTES
MEAN TIME TO PERFORM STANDARD MANEUVER = 1 MIN.
MEAN TIME TO PICK UP ONE MAN FROM WATER = 1 MIN.
RATED HEEL ANGLE OF RESCUE BOAT DAVITS = 20 DEGS.
RATED SEA STATE CAPABILITY = 20 FT. SIGN . WAVE HGT.

EXPLOSION & SINKING
ON AVG.: 10 % OF CREW KILLED BY CASUALTY
1 CREWMEN KNOCKED OVERBOARD
5 % OF CREW ISOLATED FROM LIFEBOATS
10 % OF LIFEBOATS DAMAGED
20 MIN. FROM BEGINNING OF CASUALTY TO BEGINNING OF ABANDON SHIP.
20 DEGREES HEEL ANGLE

RESULTS OF 300 SIMULTIONS:

OVERALL FRACTION OF MEN IN WATER RESCUED BY RESCUE BOAT: * .308 *

	NO. TIMES	MEAN	MIN.	MAX.
NO. IN WATER, N	300	3.01	0	6
NO. RESCUED BY BOAT,NS	186	1.49	0	5
RATIO NS/N	186	.49	0	1
RESCUE BOAT DAMAGED	15			
R.B. LAUNCH FAILED	99			
*NRBRB , ALL BOATS FILLED TO CAPACITY BEFORE LAUNCH	0		---	---
*NRBRB, RESCUE BOAT & ALL BOATS & RAFTS IN WATER FILLED TO CAPACITY	0		---	---

FIGURE 6-18

as six people in the water. This is consistent with the characteristics modeled of the explosion and sinking type casualty since on the average one man is blown overboard by the explosion and five percent of the 40 man crew, or two men, are isolated from the lifeboats and have to abandon ship by jumping overboard. The rescue boat was able to perform the rescue task in only 186 of the 300 incidents because in 15 incidents the boat was damaged by the explosion and in 99 incidents the rescue boat launch failed due to the combined effects of the sea state and the ship's heel angle during sinking.

It is also observed in Figure 6-18 that there were no incidents where people in the water were not able to be rescued by the rescue boat due to a lack of boat or raft capacity. This is so because any combination of two of the containership's two lifeboats, liferaft, and fifteen-man rescue boat provides sufficient capacity for all people on board. Thus, three of the ship's four survival craft would have to be lost (which is an unlikely event) for there to be insufficient capacity.

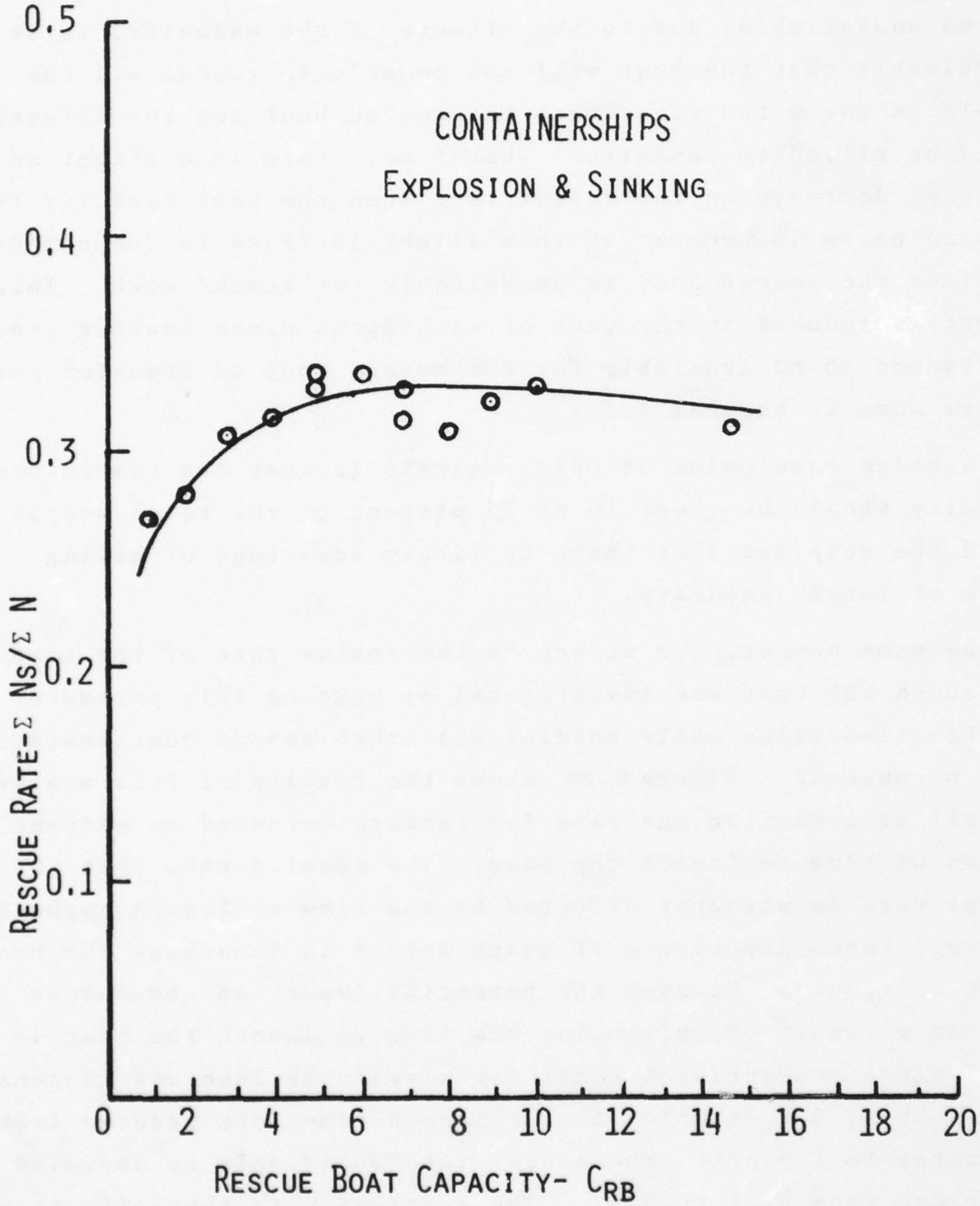
Of the 186 incidents when the rescue boat was available, it succeeded in rescuing an average of 1.49 people per incident, for an average of 49 percent of the people in the water each time. In individual simulations the boat rescued as few as none and as many as five people from the water.

The capacity of the rescue boat in the baseline case was postulated to be 15 men plus the two man crew. Since no more than 6 people were in the water in any one incident this capacity is more than adequate. It is also a reasonable capacity since a standard ship's lifeboat can easily accommodate that many. It is apparent then, that the rescue rate would only be affected when the boat's capacity falls below five since this is the most that the fifteen-man capacity boat ever rescued. The simulation was rerun changing only the boat capacity. A plot of the results

given as the rescue rate versus the boat capacity is shown in Figure 6-19. The results show a drop in the rescue rate, as expected, when the capacity is reduced below five persons. In cases when the capacity of the boat is less than 13 and both lifeboats become unavailable, due to the effects of the casualty, it is conceivable that the boat will not be able to rescue all the people in the water since both the rescue boat and the liferaft could be filled to capacity. Therefore, there is a slight additional decrease in the rescue rate when the boat capacity is reduced below 13 because of this slight increase in the number of times the rescue boat is unavailable for rescue work. This effect is reduced in the case of collisions since another vessel is assumed to be available for the rescue boat to transfer survivors when it becomes full.

A tentative c clusion of this analysis is that the rescue boat capacity should be about 10 to 15 percent of the total people on board the ship and that there is little advantage of having boats of larger capacity.

In the same manner, the effect on the rescue rate of the time to launch the boat was investigated by varying this parameter from the baseline value while holding all other rescue boat characteristics constant. Figure 6-20 shows the results of this analysis as well as a similar analysis for tankers extended to extreme values of time to launch the boat. The results show that the rescue rate is strongly affected by the time to launch emphasizing the well known importance of quick action in launching the boat in an emergency. However the potential impact on the rescue rate as a result of shortening the time to launch the boat is small since conventional boats can already be launched reasonably fast. Thus, for example, if the launch time were reduced from 2 minutes to 1 minute, the rescue rate would only be improved 3 percent from 0.31 to 0.32. The conclusion is that efforts to drastically shorten time to launch, if made at the expense of improvements in other areas, may yield disappointing results.



CONTAINERSHIPS
EXPLOSION & SINKING
0.5
0.4
0.3
0.2
0.1
RESCUE RATE-Σ Ns/Σ N
0
2
4
6
8
10
12
14
16
18
20
RESCUE BOAT CAPACITY- C_{RB}

FIGURE 6-19

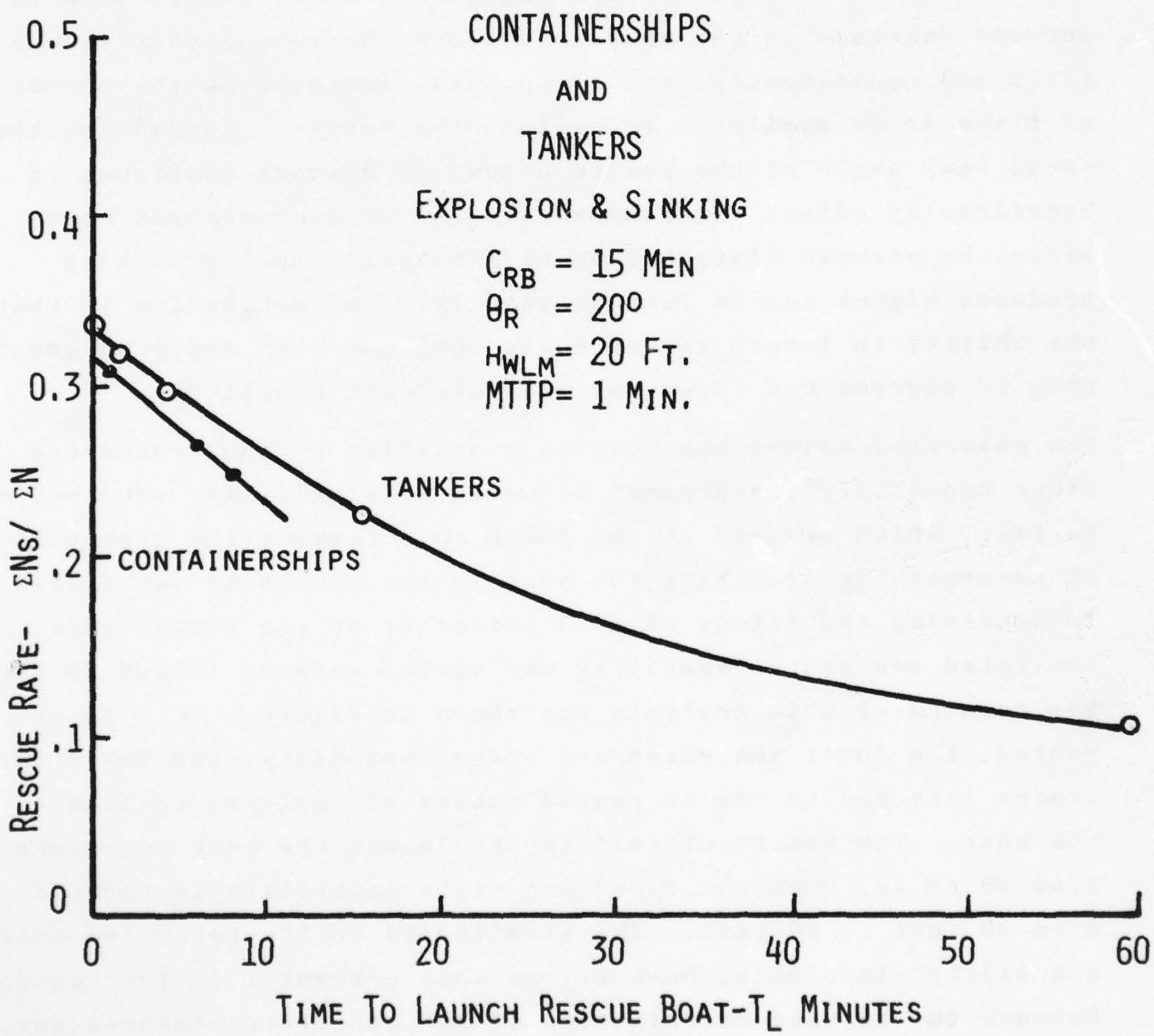
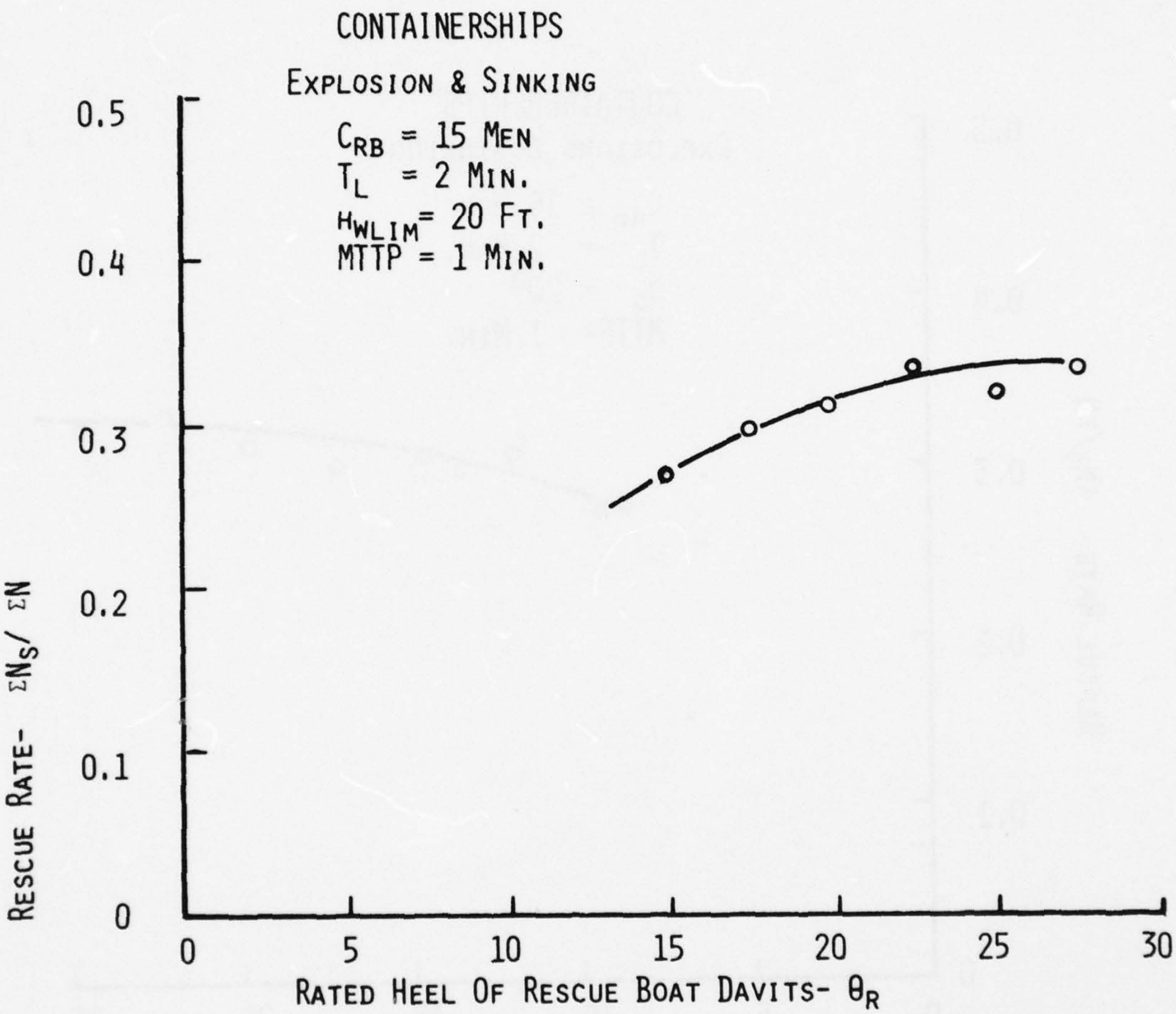

CONTAINERSHIPS
AND
TANKERS
EXPLOSION & SINKING
C_{RB} = 15 MEN
θ_R = 20^o
H_{WLM}= 20 FT.
MTTP= 1 MIN.
TANKERS
CONTAINERSHIPS
RESCUE RATE- $\Sigma Ns / \Sigma N$
0.5
0.4
0.3
.2
.1
0
0
10
20
30
40
50
60
TIME TO LAUNCH RESCUE BOAT-T_L MINUTES

FIGURE 6-20

Current U.S.C.G. regulations require davits to be fully operational at heel angles up to 15 degrees. To examine the effect of higher values of this requirement on the rescue rate, the rated heel angle of the rescue boat davits was varied between 15 and 27.5 degrees while holding all other parameters constant at the values of the baseline case. Figure 6-21 indicates that a 15 percent improvement of the rescue rate, from 0.267 to 0.308 would result from an increase in the rated heel angle from 15 degrees to 20 degrees. This 5 degree increase results in a 25 percent decrease in the number of times the rescue boat launch fails and consequently, a corresponding increase in the number of times it is available to perform the rescue. Increasing the rated heel angle of the davits beyond 20 degrees continues to beneficially affect the rescue rate but at a decreasing rate since the assumed distribution of heel angle during sinking produces higher angles less frequently. The conclusion is that the ability to launch rescue boats when the heel angle is greater than 15 degrees has potentially significant benefits.

The seaworthiness of the boat is quantified by the "rated sea state capability", expressed in units of significant wave height in feet, which is used in the ASCSM to determine the probability of successfully launching the boat in the simulated sea state. To determine the effect of this parameter on the rescue rate, the rated sea state capability was varied between 10 and 25 feet. The results of this analysis are shown in Figure 6-22 As expected, the lower the rated sea state capability, the lower the rescue rate due to the increased number of failures to launch the boat. The number of failures to launch the boat increases from 99 to 123 when the rated sea state capability is reduced from 20 feet to 10 feet. The sensitivity to the rated sea state capability diminishes, however, as this parameter is increased because the assumed distribution of the sea state produces very high wave heights less frequently. The conclusion is that while


CONTAINERSHIPS
EXPLOSION & SINKING
C_{RB} = 15 MEN
T_L = 2 MIN.
H_{WLIM} = 20 FT.
MTTP = 1 MIN.
0.5
0.4
0.3
0.2
0.1
0
RESCUE RATE- $\Sigma N_S / \Sigma N$
0
5
10
15
20
25
30
RATED HEEL OF RESCUE BOAT DAVITS- θ_R
FIGURE 6-21

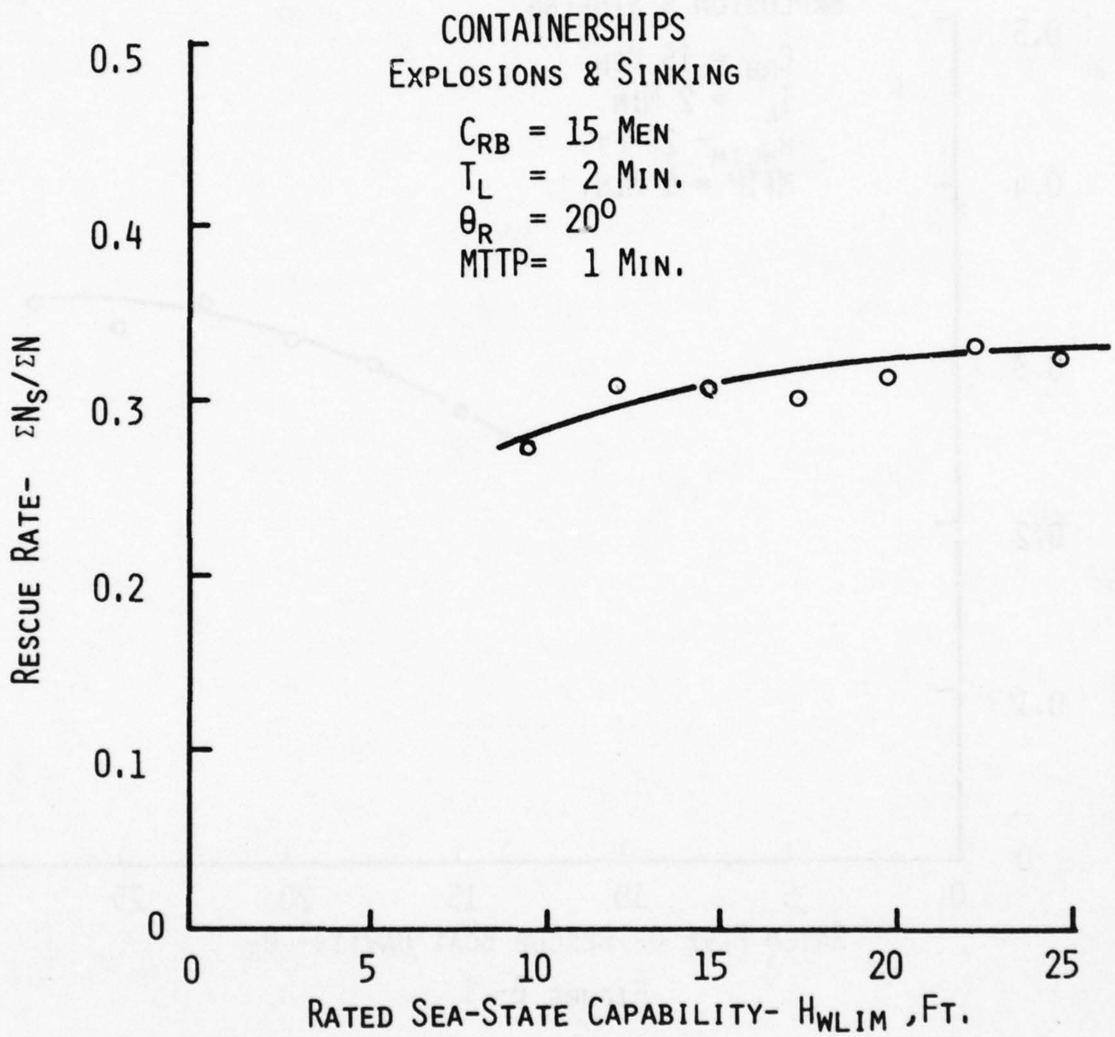

CONTAINERSHIPS
Explosions & Sinking
C_{RB} = 15 Men
T_L = 2 Min.
θ_R = 20^0
MTTP= 1 Min.
0.5
0.4
0.3
0.2
0.1
0
Rescue Rate- $\Sigma N_S/\Sigma N$
0
5
10
15
20
25
Rated Sea-State Capability- H_{WLIM} ,Ft.

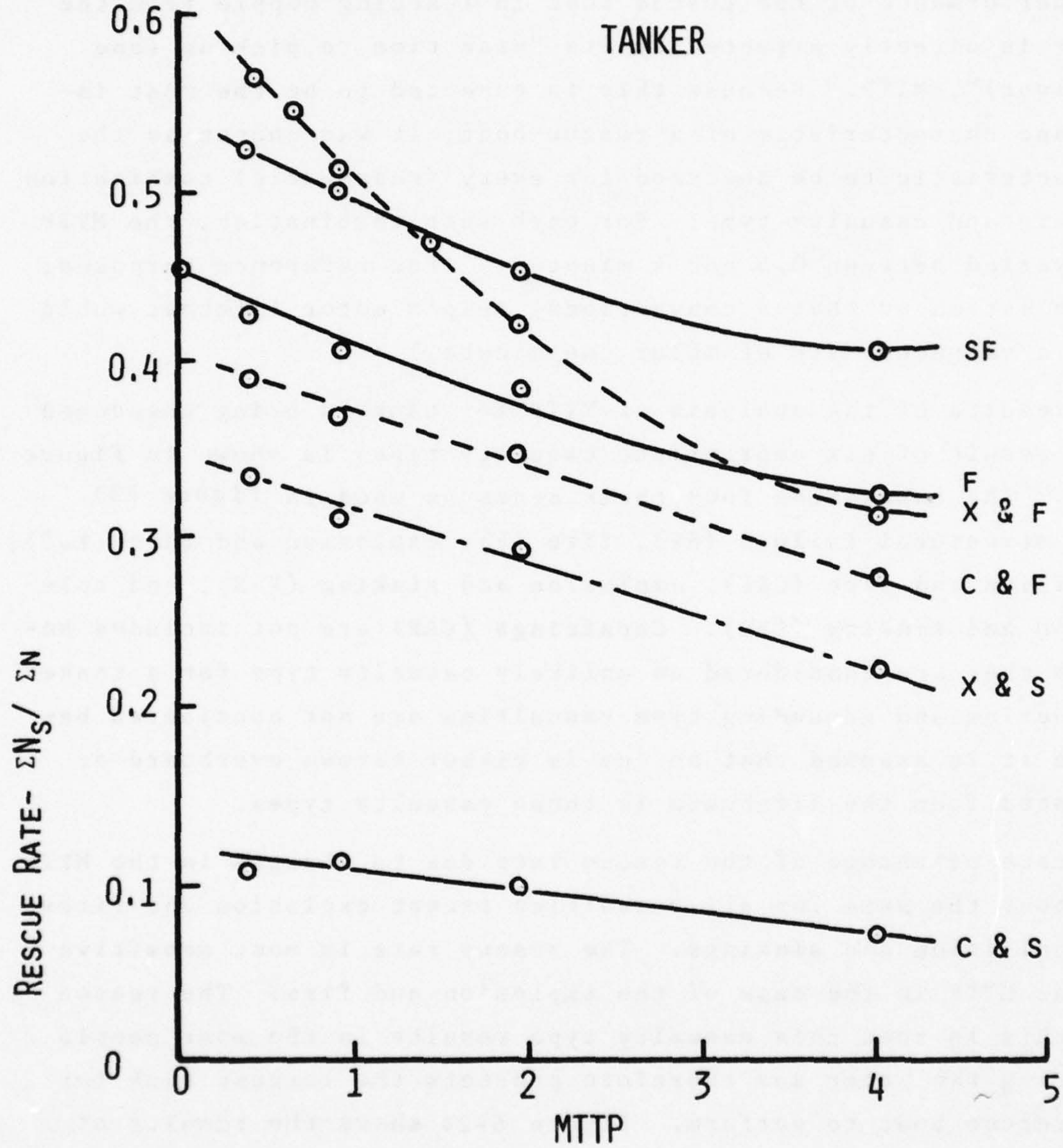
Figure 6-22

a reasonable degree of seaworthiness is important, great improvements in the seaworthiness of rescue boats can result in only a small decrease in the number of people lost during abandon ship incidents.

The performance of the rescue boat in rescuing people from the water is directly affected by its "mean time to pick up (one survivor)", MTTP. Because this is expected to be the most important characteristic of a rescue boat, it was chosen as the characteristic to be analyzed for every (reasonable) combination of ship and casualty type. For each such combination, the MTTP was varied between 0.5 and 4 minutes. (For reference purposes, it is estimated that a conventional ship's motor lifeboat would have a value of MTTP of about one minute.)

The results of the analysis of MTTP for tankers being abandoned as a result of six appropriate casualty types is shown in Figure 6-23. The casualties (and their codes as used in Figure 23) are: structural failure (SF), fire (F), explosion and fire (X&F), collision and fire (C&F), explosion and sinking (X&S), and collision and sinking (C&S). Capsizings (CAP) are not included because they are considered an unlikely casualty type for a tanker. Foundering and grounding type casualties are not considered because it is assumed that no one is either thrown overboard or isolated from the lifeboats in these casualty types.

The rate of change of the rescue rate due to changes in the MTTP is about the same for all casualties except explosion and fires and collision and sinkings. The rescue rate is most sensitive to the MTTP in the case of the explosion and fire. The reason for this is that this casualty type results in the most people entering the water and therefore presents the largest task for the rescue boat to perform. Figure 6-24 shows the results of the simulation of explosion and fire casualties on tankers with the MTTP set at one minute. The casualty statistics indicate



TANKER
0.6
0.5
0.4
0.3
0.2
0.1
0
RESCUE RATE- $\Sigma N_S / \Sigma N$
SF
F
X & F
C & F
X & S
C & S
0
1
2
3
4
5
MTTP

FIGURE 6-23

ABANDON SHIP SIMULATION

SIMULATION SERIAL NO. AS 301

TANKER
LBP = 845 FEET
POB = 40
4 - 33 MAN LIFEBOATS
1 - 25 MAN LIFERAFTS

NUMBER OF RESCUE BOATS = 1
RESCUE BOAT CAPACITY = 15 + 2 MAN CREW (EACH BOAT)
MEAN TIME TO LAUNCH RESCUE BOAT = 2 MINUTES
MEAN TIME TO PERFORM STANDARD MANEUVER = 1 MIN.
MEAN TIME TO PICK UP ONE MAN FROM WATER = 1 MIN.
RATED HEEL ANGLE OF RESCUE BOAT DAVITS = 20 DEGS.
RATED SEA STATE CAPABILITY = 20 FT. SIGN . WAVE HGT.

EXPLOSION & FIRE
ON AVG.: 10 % OF CREW KILLED BY CASUALTY
1 CREWMEN KNOCKED OVERBOARD
5 % OF CREW ISOLATED FROM LIFEBOATS
10 % OF LIFEBOATS DAMAGED
5 MIN. FROM BEGINNING OF CASUALTY
TO BEGINNING OF ABANDON SHIP.

RESULTS OF 600 SIMULTIONS:

OVERALL FRACTION OF	********
MEN IN WATER RESCUED	* .495 *
BY RESCUE BOAT	********

	NO. TIMES	MEAN	MIN.	MAX.
NO. IN WATER, N	600	5.04	1	10
NO. RESCUED BY BOAT,NS	404	3.71	0	10
RATIO NS/N	404	.74	0	1
RESCUE BOAT DAMAGED	115			
R.B. LAUNCH FAILED	81			
*NRBRB , ALL BOATS FILLED TO CAPACITY BEFORE LAUNCH	0		---	---
*NRBRB, RESCUE BOAT & ALL BOATS & RAFTS IN WATER FILLED TO CAPACITY	0		---	---

FIGURE 6-24

that on the average one person is blown overboard, five percent of the 40 man crew is isolated from the lifeboats, and another five percent is isolated by the fire. In all, it is assumed that an average of five people are either blown overboard or have to abandon ship by jumping overboard. In Figure 6-24, which shows the results of 600 simulations, there were an average of 5.04 people in the water. On at least one occasion, ten people were in the water. The rescue rate is high at 0.495 for this casualty primarily because the casualty is fast-developing and reduces the amount of time spent in the water before a rescue attempt is made. The ship is abandoned, on the average, within five minutes after the casualty occurs. However, when the number of people in the water is as high as ten and the MTTP is one minute, the last man to be rescued must survive, on the average, ten minutes beyond the start of the rescue effort if he is to be saved. When the MTTP is reduced a greater percentage of the people in the water are able to be rescued each time the rescue boat is available for use. Thus, when the MTTP is reduced from 1 minute to 0.5 minutes, the rescue rate increases from 0.495 to 0.556 primarily because the average number of people saved per rescue attempt increased from 3.71 to 4.04.

The collision and sinking casualty results shown in Figure 6-23 reveal that the rescue rate is very low and that the sensitivity of the rescue rate to changes in the MTTP is also low. This is due to the fact that few people enter the water (on the average, 0.5 people are knocked overboard by the collision) and the relatively long time involved (30 minutes, on the average) for the casualty to develop before the ship is abandoned and the rescue effort is presumed to start. Thus, a change of half a minute or so in the MTTP is a relatively insignificant change in the total time period required to rescue the one man who may go in the water in this casualty type. It would be far more effective to

institute a policy to launch the rescue boat immediately after a collision, regardless of the decision to abandon the ship or not; dogmatic policies of this nature are always subject to exception, since for example, a particular situation may require the rescue boat crew to stay aboard to assist in efforts to save the ship.

The next effect of reducing the MTTP of rescue boats carried by tankers depends upon the relative frequency of occurrence and the relative numbers of lives at risk in the various types of casulaties. In general, in view of the few number of lives at risk in collision and sinkings and the general invulnerability of tankers to sinking, this casualty type should not unduly influence the type of boat to be carried. The other five casualty types all show a significant sensitivity to changes in MTTP; the explosion and fire casualty which is the most sensitive, is perhaps the most significant casualty and has the most lives at risk. The conclusion is that there are considerable opportunities for enhancement of the rescue rate during abandonment from tankers as a result of reducing the MTTP.

Figure 6-25 shows similar results from containerships being abandoned as a result of five relevent casualties. (Massive explosions, for example, are not considered as likely casualties for containerships.) In general, the results are about the same as for tankers. The rescue rate in capsizings is about the same as for collision and sinkings since both are characterized by only a few people entering the water at the time the casualty occurs. The sensitivity of the rescue rate to the MTTP is greater for capsizing, however, since this casualty develops faster and a change in the time to perform the rescue is a more significant portion of the total time the man must spend in the water.

The results of the analysis for LNG ships is shown in Figure 6-26 and is quite similar to the results for tankers.

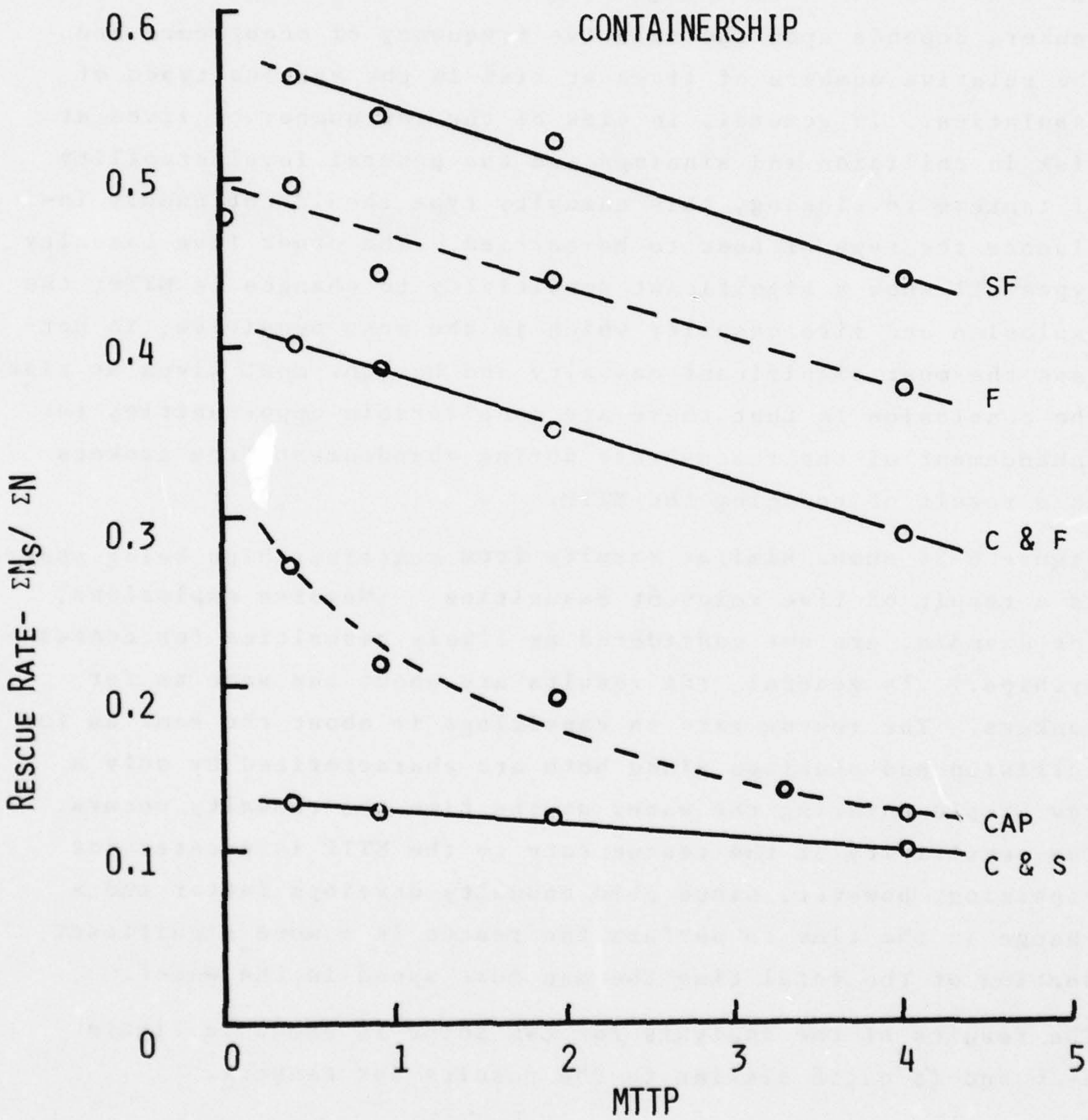
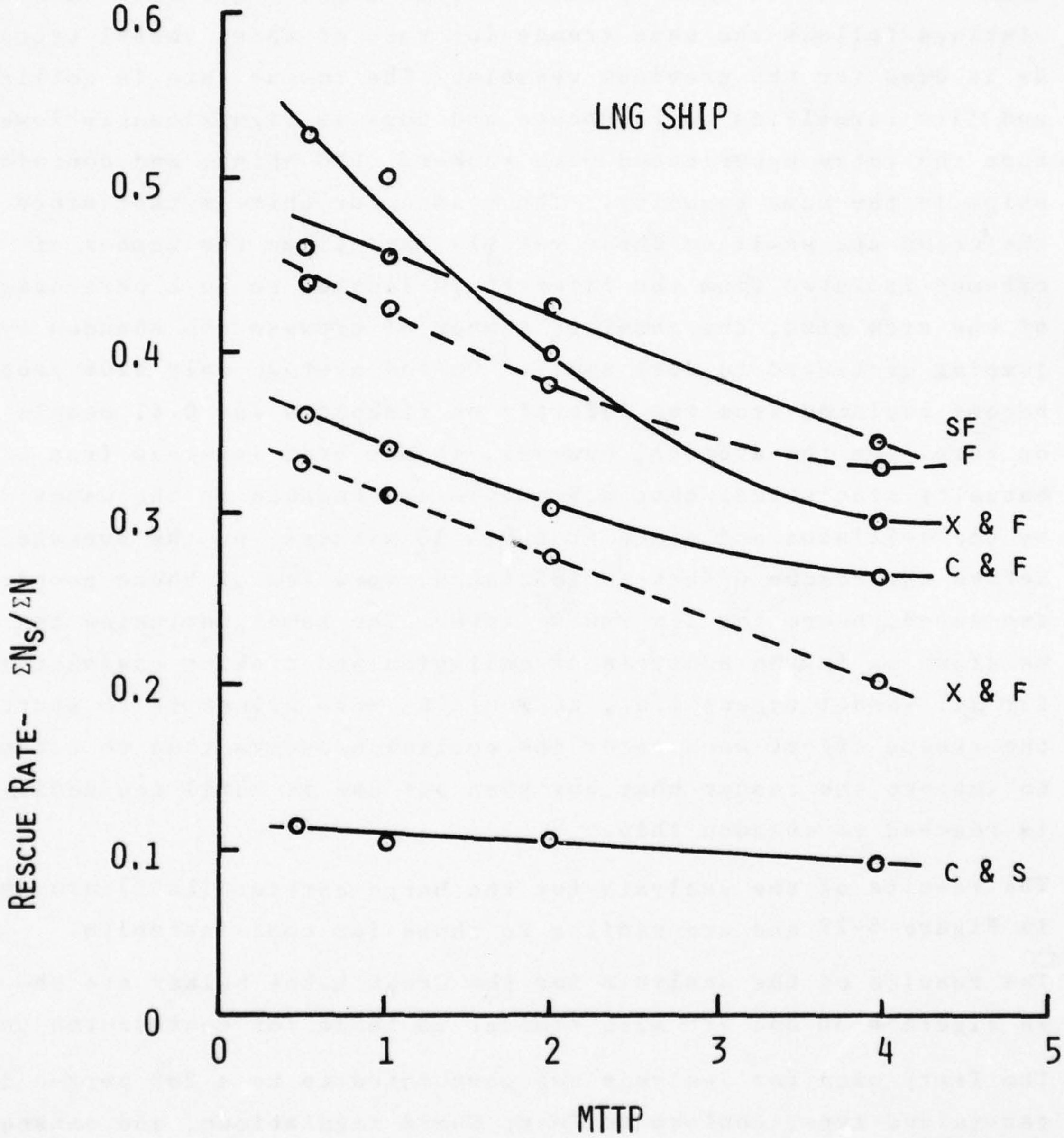

CONTAINERSHIP
0.6
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
SF
F
C & F
CAP
C & S
RESCUE RATE- $\Sigma N_S / \Sigma N$
MTTP

FIGURE 6-25



LNG SHIP
0.6
0.5
0.4
0.3
0.2
0.1
0
RESCUE RATE- $\Sigma N_S/\Sigma N$
SF
F
X & F
C & F
X & F
C & S
0
1
2
3
4
5
MTTP

FIGURE 6-26

For fishboats and tugs only four casualty types are considered appropriate: fire, capsizing, collision and fire, and collision and sinking. The results of the analyses for these two vessel types are shown in Figures 6-27 and 6-28 The effect of the MTTP on the rescue rate in fires, capsizings, and collision and sinkings follows the same trends for both of these vessel types as it does for the previous vessels. The rescue rate in collision and fire casualties on fishboats and tugs is significantly lower than the rates experienced with tankers, LNG ships, and containerships in the same casualty. The reason for this is that since the crews are small on these vessels, and since the number of crewmen isolated from the liferaft is assumed to be a percentage of the crew size, the absolute number of crewmen who abandon by jumping overboard is very small. On the average only 0.06 people become isolated from the liferaft on fishboats and 0.61 people on tugs. On the average, however, it has been inferred from casualty statistics, that 0.5 people are knocked in the water by the collision and since it takes 30 minutes, on the average, before the rescue effort is initiated, very few of these people are saved, hence the low rescue rate. The same conclusion can be drawn as in the analysis of collision and sinking casualties for all vessel types; i.e., it would be more effective to start the rescue effort soon after the collision occurs than to attempt to improve the rescue boat but then not use it until the decision is reached to abandon ship.

The results of the analysis for the barge carrier (LASH) are shown in Figure 6-29 and are similar to those for containerships.

The results of the analysis for the Great Lakes bulker are shown in Figure 6-30 and are also similar to those for containerships.

The ferry used for analysis was postulated to be a 200 person inter-island type, conform to Coast Guard regulations, and consequently carry eight 25-man liferafts thereby providing capacity for

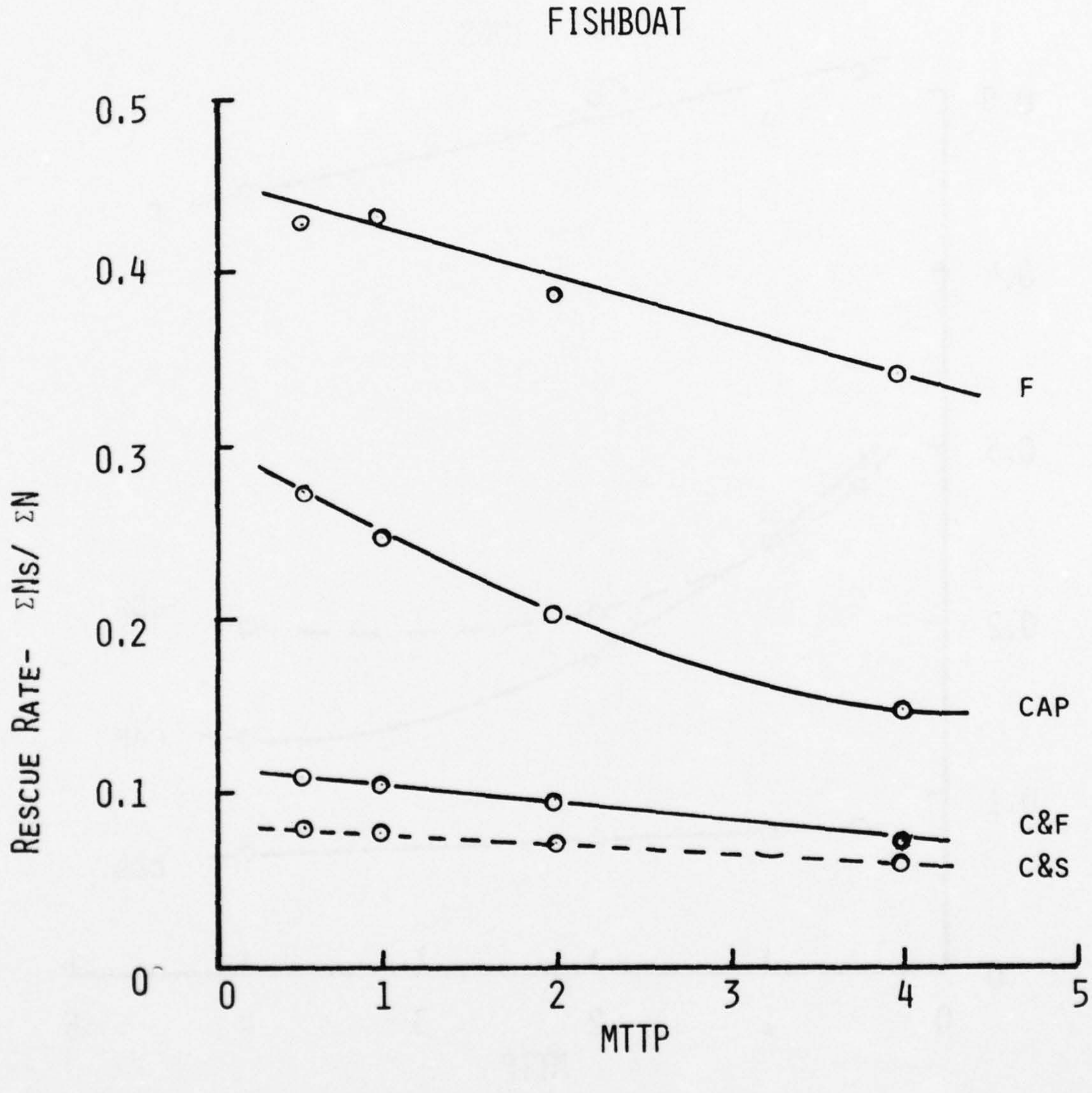

FISHBOAT
0.5
0.4
0.3
0.2
0.1
0
RESCUE RATE- ΣNs/ ΣN
F
CAP
C&F
C&S
0
1
2
3
4
5
MTTP

FIGURE 6-27

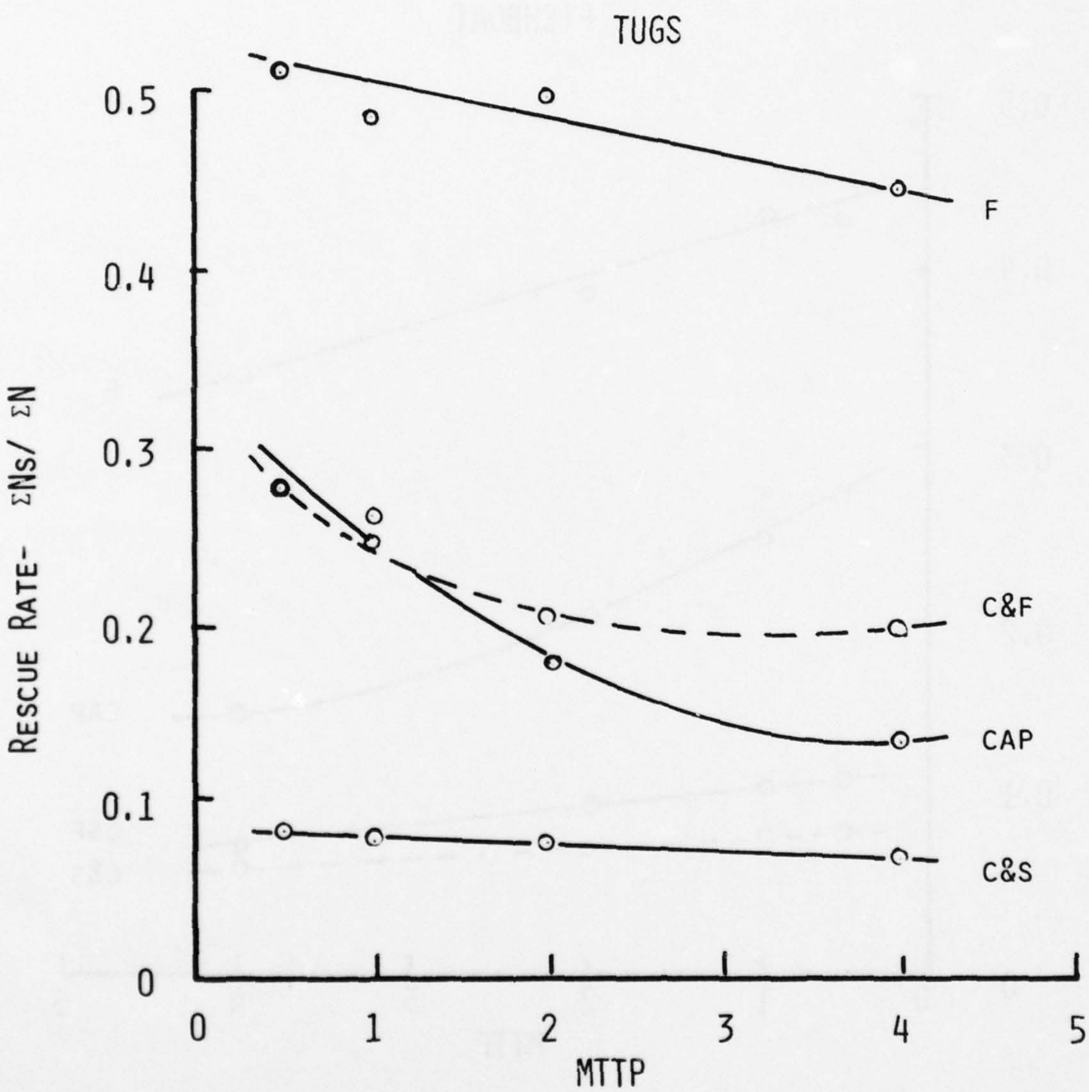
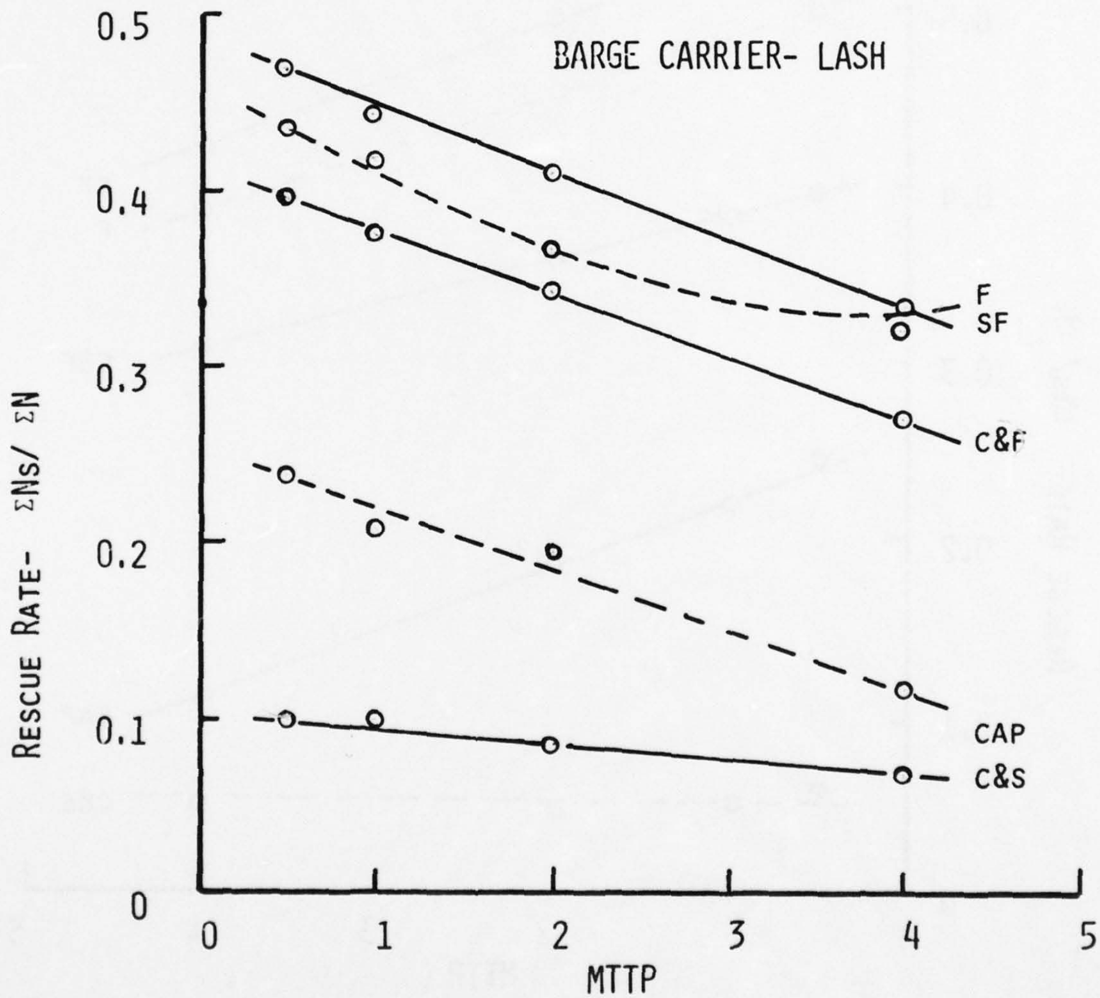


FIGURE 6-28



BARGE CARRIER- LASH
0.5
0.4
0.3
0.2
0.1
0
RESCUE RATE- ΣNs/ ΣN
F
SF
C&F
CAP
C&S
0
1
2
3
4
5
MTTP

FIGURE 6-29

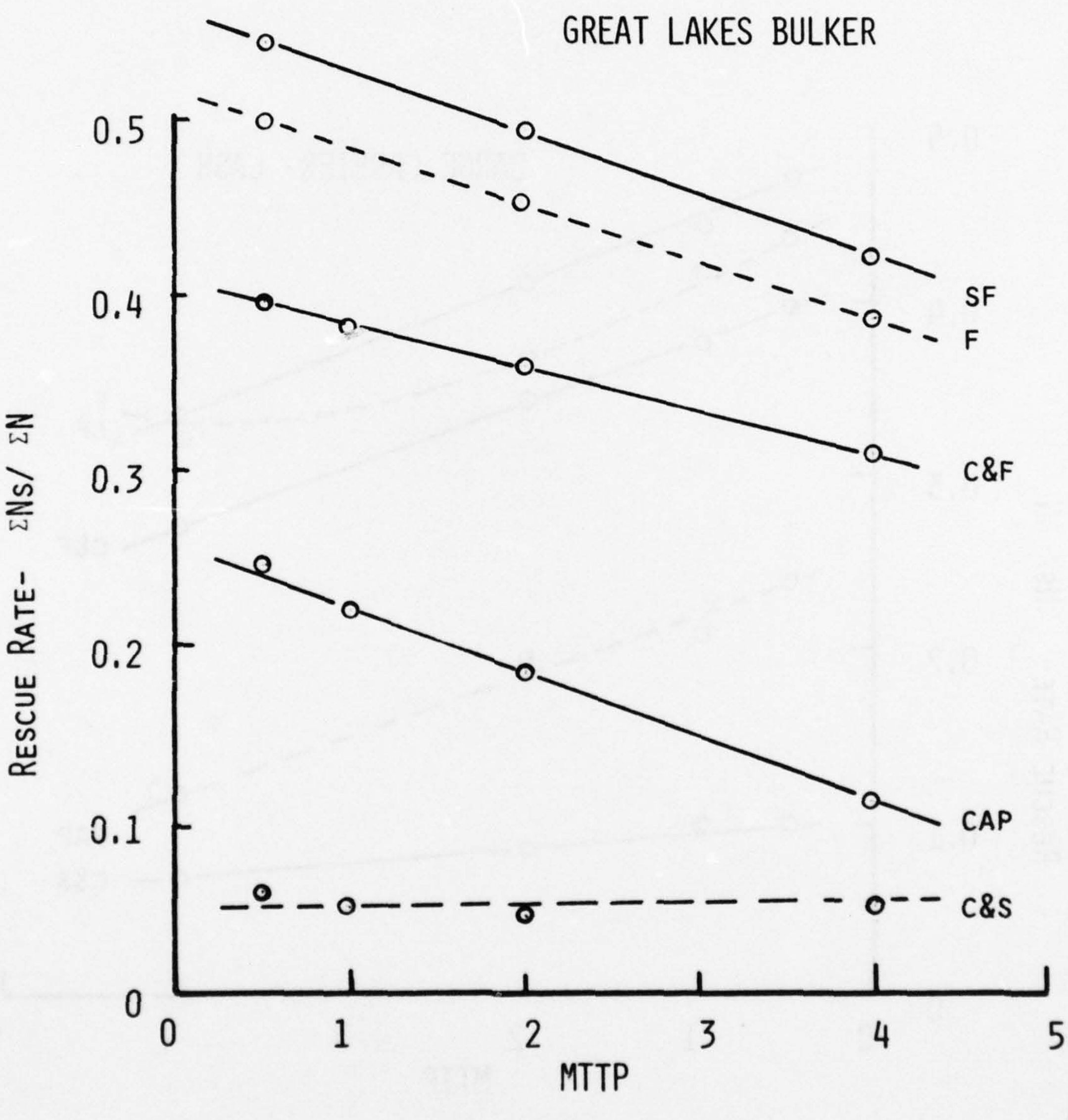

GREAT LAKES BULKER
RESCUE RATE- ΣNs/ ΣN
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
MTTP
SF
F
C&F
CAP
C&S

FIGURE 6-30

100 percent of the persons on board. The rescue boat carried was presumed to have a three-person capacity plus a two-man crew.

The results of the analysis are shown in Figure 6-31 The rescue rate is very low for each of the four casualty types. The reason for this can be seen in the output sheet for the simulation of fires with a rescue boat MTTP value of one minute (simulation serial no. AS 269) shown in Figure 6-32 It can be seen that, on the average, 34 percent of the people in the water are saved when the rescue boat is available; however, the boat is only available for rescue in 48 of the 300 incidents simulated. The boat's launch, according to the simulation findings, failed 37 times and on 232 occasions the boat was filled to capacity and therefore unable to rescue the people in the water. The rescue boat becomes filled to capacity whenever one or more of the 25-man liferafts is damaged. Furthermore, the number of people represented by the difference between the capacity of the damaged liferafts and the rescue boat's total capacity have no means of abandoning ship other than by jumping. The low rescue rates for abandon ship casualties on ferries is therefore not a function of rescue boat performance as such but instead is heavily influenced by the degree of redundancy in the basic lifeboat/liferaft suit. This redundancy could, of course, be provided by the rescue boat provided that the rescue boat had sufficient capacity to substitute for one or more damaged liferafts and for the people retrieved from the water.

The effect of more than one rescue boat on the rescue rate was analyzed using the standard ferry involved in a fire type of casualty. The results are shown in Figure 6-33 This analysis also demonstrates the analysis of two parameters since the comparison of the rescue rate with one and two boats is made between curves of rescue rate versus MTTP. With MTTP equal to one minute, the rescue rate is nearly doubled by adding a second boat.

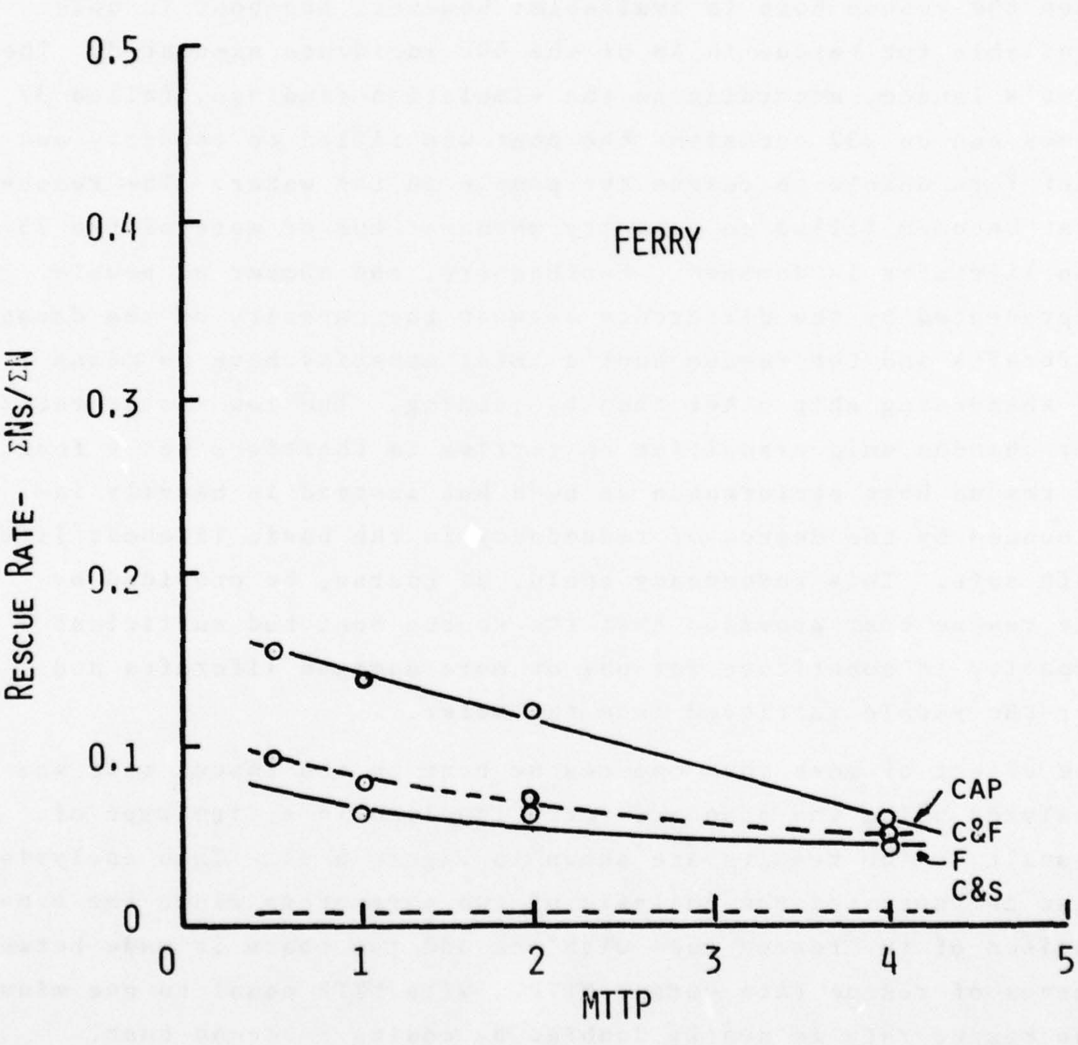


FIGURE 6-31

ABANDON SHIP SIMULATION

SIMULATION SERIAL NO. AS 269

FERRY
LBP = 150 FEET
POB = 200
0 - 10 MAN LIFEBOATS
8 - 25 MAN LIFERAFTS

NUMBER OF RESCUE BOATS = 1
RESCUE BOAT CAPACITY = 3 + 2 MAN CREW (EACH BOAT)
MEAN TIME TO LAUNCH RESCUE BOAT = 2 MINUTES
MEAN TIME TO PERFORM STANDARD MANEUVER = 1 MIN.
MEAN TIME TO PICK UP ONE MAN FROM WATER = 1 MIN.
RATED HEEL ANGLE OF RESCUE BOAT DAVITS = 20 DEGS.
RATED SEA STATE CAPABILITY = 20 FT. SIGN . WAVE HGT.

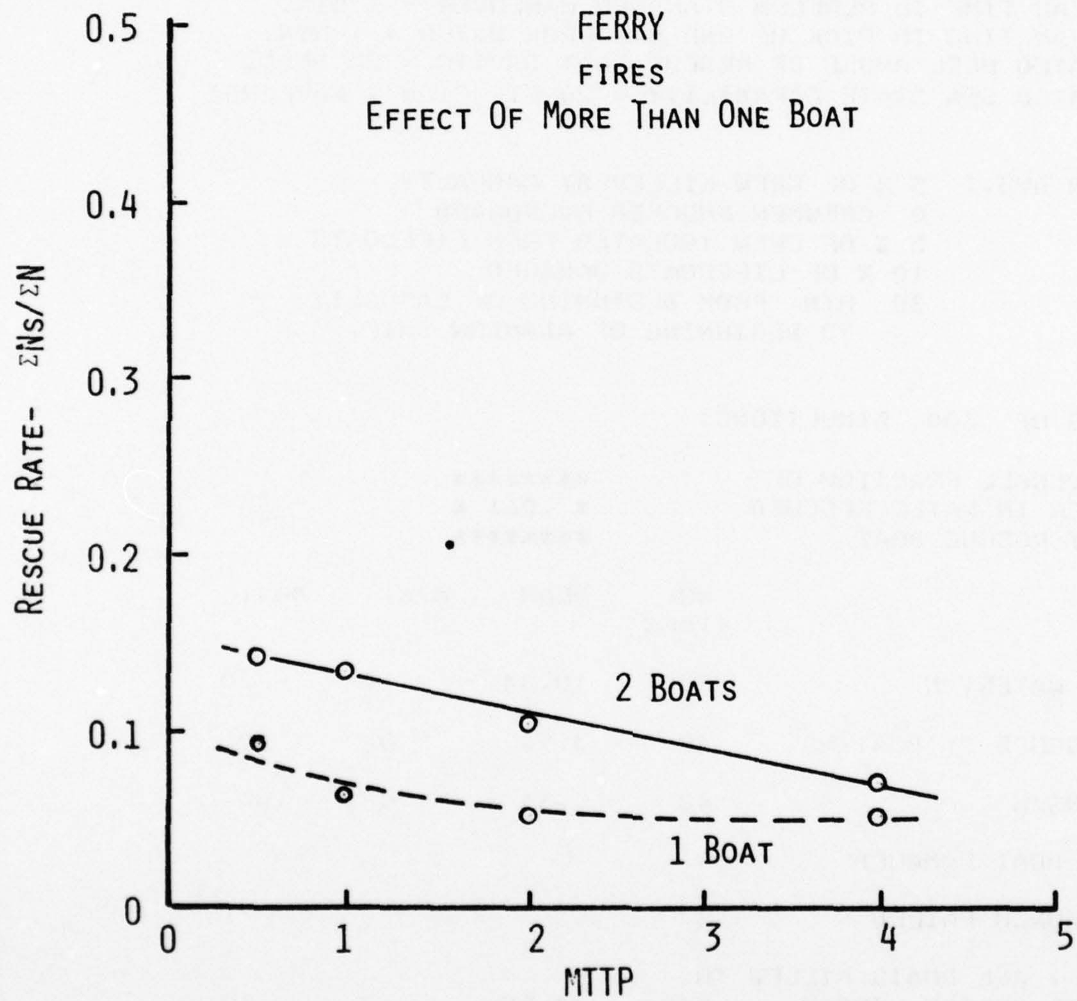
FIRE
ON AVG.: 5 % OF CREW KILLED BY CASUALTY
0 CREWMEN KNOCKED OVERBOARD
5 % OF CREW ISOLATED FROM LIFEBOATS
10 % OF LIFEBOATS DAMAGED
30 MIN. FROM BEGINNING OF CASUALTY TO BEGINNING OF ABANDON SHIP.

RESULTS OF 300 SIMULTIONS:

OVERALL FRACTION OF MEN IN WATER RESCUED BY RESCUE BOAT
****
* .061 *
****

	NO. TIMES	MEAN	MIN.	MAX.
NO. IN WATER, N	300	10.44	0	20
NO. RESCUED BY BOAT,NS	48	3.96	0	10
RATIO NS/N	48	.34	0	.88
RESCUE BOAT DAMAGED	0			
R.B. LAUNCH FAILED	37			
*NRBRB , ALL BOATS FILLED TO CAPACITY BEFORE LAUNCH	215	33.35	2	62
*NRBRB, RESCUE BOAT & ALL BOATS & RAFTS IN WATER FILLED TO CAPACITY	17	6.82	0	12

FIGURE 32



FERRY
FIRES
EFFECT OF MORE THAN ONE BOAT
RESCUE RATE- ΣNs/ΣN
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
MTTP
2 BOATS
1 BOAT

FIGURE 6-33

Finally, the ability to analyze the effect of ship characteristics and rescue boat characteristics on the rescue rate is demonstrated by analysis of the change in the number of lifeboats and rescue boats as a function of MTTP. The results of this analysis, conducted for collision and fire type casualties on tankers, is shown in Figure 6-34. The results show that there is not substantial change in the rescue rate when the number of lifeboats is reduced from 4 to 3, i.e., when the rescue boat is considered as a substitute for one of the required lifeboats rather than an addition. When the number of lifeboats is reduced to three and the number of rescue boats is increased to two, however, a significant increase in the rescue rate occurs. Further studies should be made to determine whether the rescue rate would change if the number of lifeboats were reduced to two and the number of rescue boats held at two. Substantially different results would be expected for casualty types such as collision and sinking and capsizing in which the vessel takes on a list, thereby diminishing the probability of successfully launching the lifeboats. The conclusion can be tentatively drawn, however, that a rescue boat need not be carried in addition to a full complement of lifeboats and that there are advantages to either carrying multiple rescue boats or having lifeboats with improved rescue characteristics.

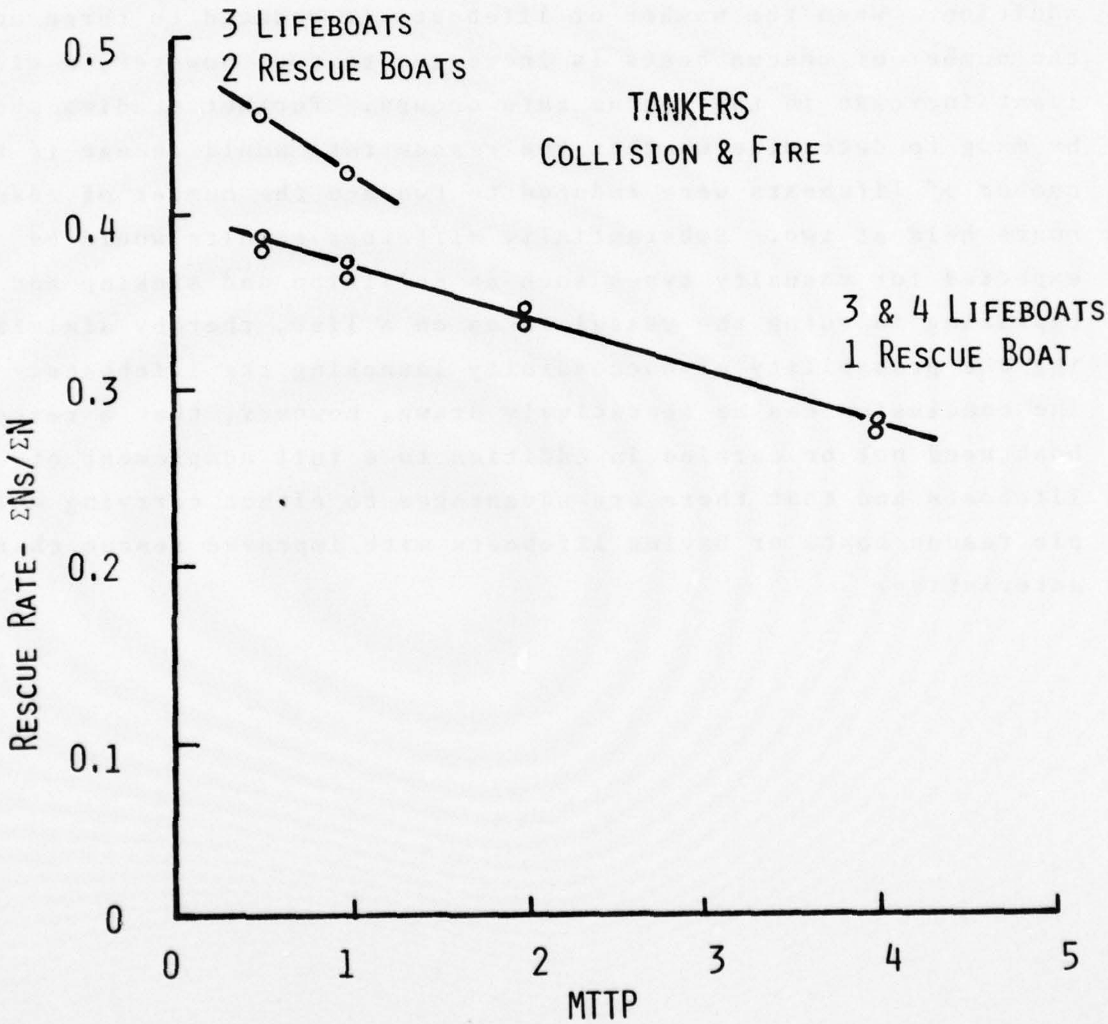

3 LIFEBOATS
2 RESCUE BOATS
TANKERS
COLLISION & FIRE
3 & 4 LIFEBOATS
1 RESCUE BOAT
RESCUE RATE- ΣNs/ΣN
0.5
0.4
0.3
0.2
0.1
0
0
1
2
3
4
5
MTTP

FIGURE 6-34

6.3 Rescue Boat Test Procedures

Additional test procedures are required over and above those presently specified in the Coast Guard regulations, to determine the effectiveness of rescue boats in rescue operations. The functional performance parameters, boat speed in waves, the MTTP and the "mean time to perform the standard maneuver", proposed as measures of the rescue boat's speed and agility are by their nature dynamic quantities. As such they must be measured dynamically. That is, they must be determined by measuring a given boat's performance on an actual, but standardized, course.

A tentative test specification for the "mean time to perform the standard maneuver" would require the boat to maneuver from the side of a vessel to a buoy located one hundred yards abeam and fifty yards ahead of the starting point. The heading at the starting point would be into the seas. The boat would be required to proceed at its best speed and heading to the buoy, stop and hold its position alongside for at least fifteen seconds in a nominal sea with wave heights of three feet (average of the one third highest). A wave height meter would be used to measure the waves to ensure that the significant wave height remained within $\pm$ 0.5 feet during the test. The course would be run with three or more different coxswains selected at random from certified lifeboatmen but with no additional expertise as coxswains. Each coxswain would run the course at least three times. The rated "mean time to perform the standard maneuver" would be the average of the six fastest times.

A tentative test specification for the "mean time to pick up one survivor" (MTTP) would require the boat to maneuver from the side of a vessel to six buoys arranged in a specified pattern. The buoys pattern would be so arranged that their spacing would be between 50 and 500 yards apart. At each buoy the rescue boat crew would be required to lift aboard a 150 pound dummy wearing

a PFD and attached to the buoy with a quick release clip. The sea conditions and coxswain selection would be the same as in the standard maneuver test. The rated MTTP would be determined by computing the average of the six fastest times.

A third proposed measure of rescue boat performance requiring testing is the speed in waves. This can be obtained by running standard measured mile speed trials in seas high enough to obtain at least a twenty-five percent speed loss while measuring the wave heights with a wave meter.

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7. Comstock, J.P., "Principles of Naval Architecture", The Society of Naval Architects and Marine Engineers, 1967.

8. Title 46, Code of Federal Regulations, Chapter I, Subchapters C, D, E, H, I, and T, U.S. Coast Guard.

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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
in	inches	*2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
		AREA		
in^2	square inches	6.5	square centimeters	cm^2
ft^2	square feet	0.09	square meters	m^2
yd^2	square yards	0.8	square meters	m^2
mi^2	square miles	2.6	square kilometers	km^2
	acres	0.4	hectares	ha
		MASS (weight)		
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
		VOLUME		
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft^3	cubic feet	0.03	cubic meters	m^3
yd^3	cubic yards	0.76	cubic meters	m^3
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

*1 in ≡ 2.54 (exactly). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price $2.25, SD Catalog No. C13.10:286.

Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
		LENGTH		
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
		AREA		
cm^2	square centimeters	0.16	square inches	in^2
m^2	square meters	1.2	square yards	yd^2
km^2	square kilometers	0.4	square miles	mi^2
ha	hectares (10,000 m^2)	2.5	acres	
		MASS (weight)		
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
		VOLUME		
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m^3	cubic meters	35	cubic feet	ft^3
m^3	cubic meters	1.3	cubic yards	yd^3
		TEMPERATURE (exact)		
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F